NUREG-0706
Vol. III

Final Generic Environmental Impact Statement
on uranium milling
Project M-25

Appendices G-V

September 1980

Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission

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FOREWORD

Volume III contains Appendices G-V, which support the discussions in Volume I. In some cases, the appendices expound upon arguments developed in the main document. In other cases, supplementary material considered to be relevant, but not present in Volume I, is included. A third category encompasses reprinting of pertinent documents believed to be necessary for a comprehensive presentation of the current situation, e.g., Public Law 95-604.

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APPENDIX G-1. SOURCE TERM ESTIMATION

A discussion and summary of calculations for the model mill emission source terms are presented in the following subsections. By "source term" we mean simply the quantity of radioactivity (in curies, for example) released in a specified period of time. The calculated source terms are given in Table 5.5. In addition to these source terms, it also is necessary to provide other input data which describe certain physical characteristics of the radioactive material such as particle size and density. These parameters also are described in this section.

The sources of radioactive effluent that are included in this analysis of an operating uranium mill are the following: 1) the ore storage pad and grinding operation; 2) yellowcake drying and packaging; 3) tailings pile; and 4) radon from dispersed radium-bearing materials.

1. ORE PAD AND GRINDING

If one follows the sequence of processing steps through which the ore passes, the first source is a composite which includes storage on the ore pad and bins and the ore feed, crushing, and grinding operations. Each component releases particulates and radon gas.

1.1 Particulates

At the mill the ore is segregated according to uranium, clay, and organic content and the various grades of ore are then blended to produce uniform feed for the mill. The quantity of ore stored at the mill depends on the distance from the mine to the mill, anticipation of weather conditions that might limit mining and transportation of the ore, management decisions to stockpile in anticipation of strikes, etc. For the model mill, storage sufficient for ten days of continuous mill operation is assumed.

When extracted from the mine, ores typically contain from 6 to 14% moisture. The moisture content of the ore received at the mill is dependent on the duration of storage at the mine prior to shipment, the distance and means of transportation, and weather conditions. The average moisture content of the ore as it is received at the mill generally is not determined.

Windy and dry weather may dry the surface of ore stored at the mill and thereby increase the amount of fugitive dust that is released. The quantity of the airborne dust generated is dependent on the physical characteristics of the ore pad and its height relative to adjacent land, the physiography of the mill site, wind channeling, and wind shear velocity and profile. The frequency of winds in excess of 2 m/s (4.5 mph) is especially important. The rate of ore transport by wind may range from less than 10 g/hr-m to 10 kg/hr-m, while the distance travelled will depend on particle size and on wind profile, velocity, and duration.[1-6]

Estimation of the dust flux from the ore pad is further complicated by the action of ore trucks and machinery used to transport the ore to the crushing system. A study of fugitive dust production by surface coal mining reports an emission factor of 0.06 grams of dust per kilogram of material handled by a front-end loading machine.[7] The combined actions of wind and machinery may produce an airborne flux in excess of 0.1 g per kilogram of ore processed.[8] With an ore process rate of 5.6×10^5 MT/yr (6.2×10^5 ST/yr) there is the potential for large quantities of ore to become airborne; however, much of it is of a particle size greater than 100 μm and therefore will be transported only a short distance. Preliminary data, shown in Figure G-1.1, from measurements on a composite ore sample from one mine suggest that over 95% of the ore mass consists of nonsuspendible particles greater than 100 μm in diameter. Below, in Section 3.1, it is estimated that the mass flux of suspendible particles leaving dry tailings surfaces is 3.7 MT/ha-yr. For the 0.5-ha ore pad, dusting at this rate would yield a total emission of about 1.9 MT/yr. Because of the reduced abundance of suspendible particle sizes, relative to tailings sands, and the likelihood of greater surface moisture content, the dusting rate from the ore pad is estimated to be about 20 percent of that for exposed tailings surfaces, or about 0.7 MT/ha-yr. Total dust production from all sources is assumed to be about three times that produced by wind action alone, or about 2 MT/ha-yr.[8] Dust emission from the 0.5-ha ore pad is therefore estimated to be about 1 MT/yr.

Transport of ore to the grizzly and crushing and screening also are sources of dust. Some of these processes are carried out in buildings and the dust-loaded air is ventilated through

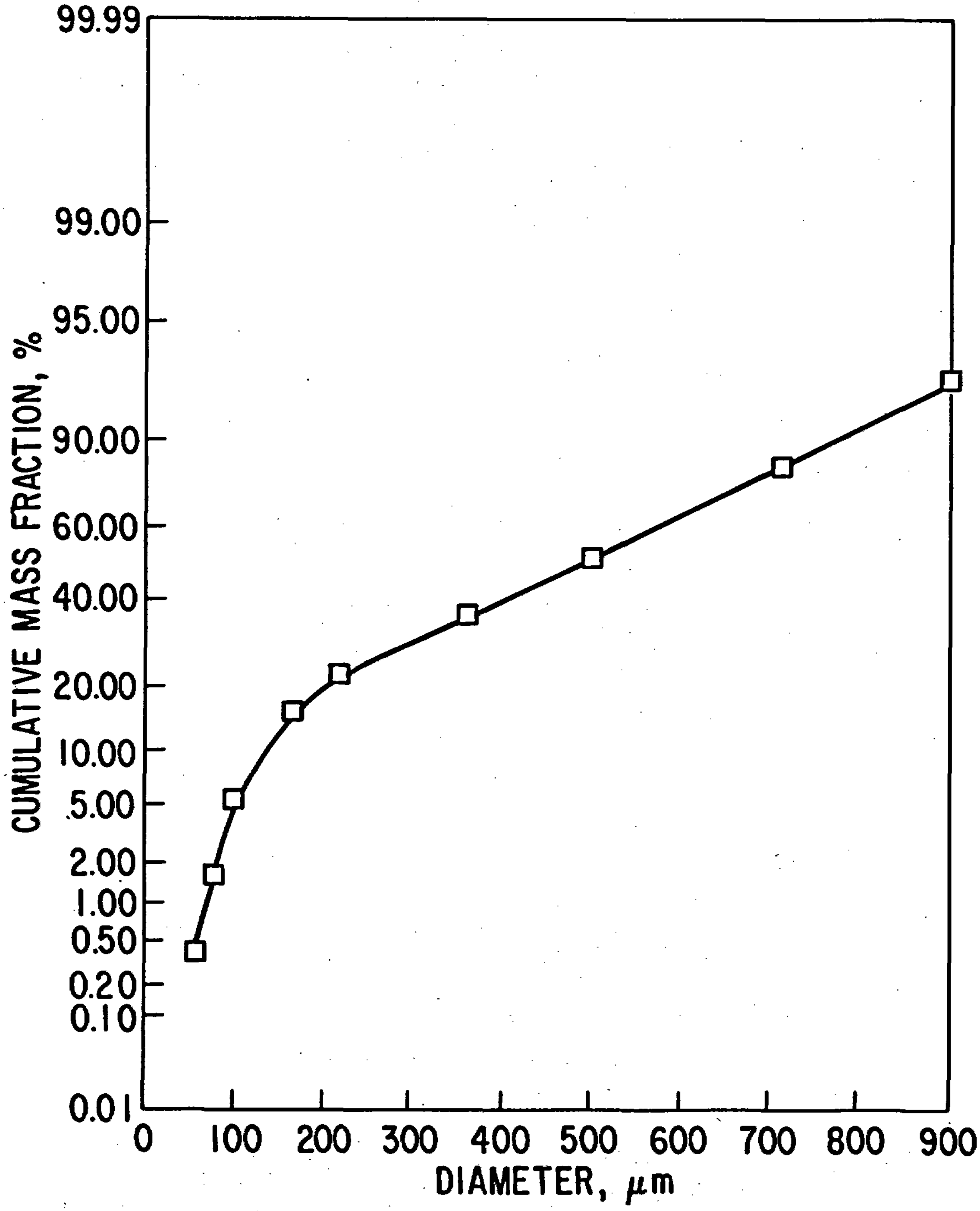

Fig. G-1.1. Particle Size Distribution of Composite Uranium Ore Feed.

control systems so that the quantity of dust released into the atmosphere is a small fraction of that generated. The crushed ore is transported by a conveyor belt to a crusher, which in the base case utilizes a "dry" process. Again, in this type of operation only a small fraction of the fine dust escapes into the atmosphere. A variety of air cleaning devices are utilized in existing mills to reduce dust emission from the crushing and grinding operation.[10] In the base case, a wet impingement scrubber with an average efficiency for dust collection of 97% is employed.[11] Sears et al.[10] have reported on the extent to which the amount of dust generated depends on the moisture content of the ore and have shown that for an average ore moisture content of 6 percent about 0.008 percent of the total ore mass processed will be lost as dust to exhaust air ventilation flow. Based on a 97 percent removal efficiency and an ore processing rate of 5.6×10^5 MT/yr, ore dust losses to the atmosphere will amount to about 1.3 MT/yr.

Total dust emissions from ore pad operation, and crushing and grinding, are thus estimated to be 2.3 MT/yr. The ratio of the radioactivity content of the fine dusts released to that of the bulk ore is estimated to be 2.4, based on data presented in Reference 10 and supported by data presented here in Figure G-1.2. Since the bulk ore activity of U-238 and each radioactive daughter is 280 pCi/g, the specific activity of the released dust is estimated to be 672 pCi/g. Total annual radioactivity releases are estimated as follows for U-238 and each radioactive daughter:

$$2.3 \text{ MT/yr} \times 10^6 \text{ g/MT} \times 672 \text{ pCi/g} \times 10^{-9} \text{ mCi/pCi} = 155 \text{ mCi/yr}$$

The particle size associated with these releases is assumed to be 1 μm. This is consistent with recommendations of the International Commission on Radiological Protection (ICRP)[12] for the case of undefined particle size distribution, such as ore pad releases, and with the general efficiency of air cleaning devices as a function of input particle size.

1.2 Radon

During the average 12-day period when the ore is stored on the pad awaiting processing, radioactive decay of radium-226 produces radon continuously. It is assumed that only 20% of the radon is available for release or emanation from the mineral grains in which it is produced (i.e., the emanating fraction or power is 0.20).[13] If none of the available radon escapes during storage, it will reach about 90% of its equilibrium concentration within twelve days. Upon movement to the grizzly and subsequent crushing and grinding, all of the accumulated radon might escape. This would amount to 30 Ci/year at an ore processing rate of 1800 MT/day. A more conservative approach is to assume that all of the radon available for release (20%) actually escapes from the ore pile as soon as it forms. This would result in the exhalation to the atmosphere of 68 Ci/year. This latter value is used for prediction of the radiological impact of the model mill, so as to account for other lesser radon sources not treated explicitly.

The amount (in picocuries) of Rn-222 available for release from each gram of ore as a result of Ra-226 decay during storage on the pad is given by the expression:

$$E[Ra]\lambda T$$

where E = emanating power, 0.2

[Ra] = concentration of Ra-226 in ore, 280 pCi/g

λ = the decay constant for Rn-222, 0.181/day

T = storage time on ore pad, 12 days (this accounts for the presence of a 10-day supply for 365 days/yr).

Since the ore process rate is 1,800 MT/day, 310 days/year, the Rn-222 emission rate is:

$$0.2 \times 280 \text{ pCi/g} \times 0.181\text{/day} \times 12 \text{ days} \times (1800 \times 310) \text{ MT/yr}$$
$$\times 10^6 \text{ g/MT} \times 10^{-12} \text{ Ci/pCi} = 68 \text{ Ci/yr.}$$

Most ore bins are enclosed and in winter are heated to prevent freezing. The ore is removed from the bottoms of the bins and transported on conveyer belts. [Currently operating mills are seldom equipped with ore dryers. It is estimated that ore dryers could release 10 to 60 times as much ore dust as the crusher complex (Ref. 10, p. 128).] Storage of ore in bins for less than one month is sufficient for the concentration of Rn-222 gas to build up to the equilibrium value of 280 μCi/MT of ore. Because these ores are crushed to relatively fine particles, the available Rn-222 (56 μCi/MT) could be released during extraction from the ore bin; however, for this analysis it is assumed that ore is blended directly on the pads for processing at the model mill and not stored in bins. In any event, contributions from ore storage bins would not significantly increase the total annual radon release from the mill.

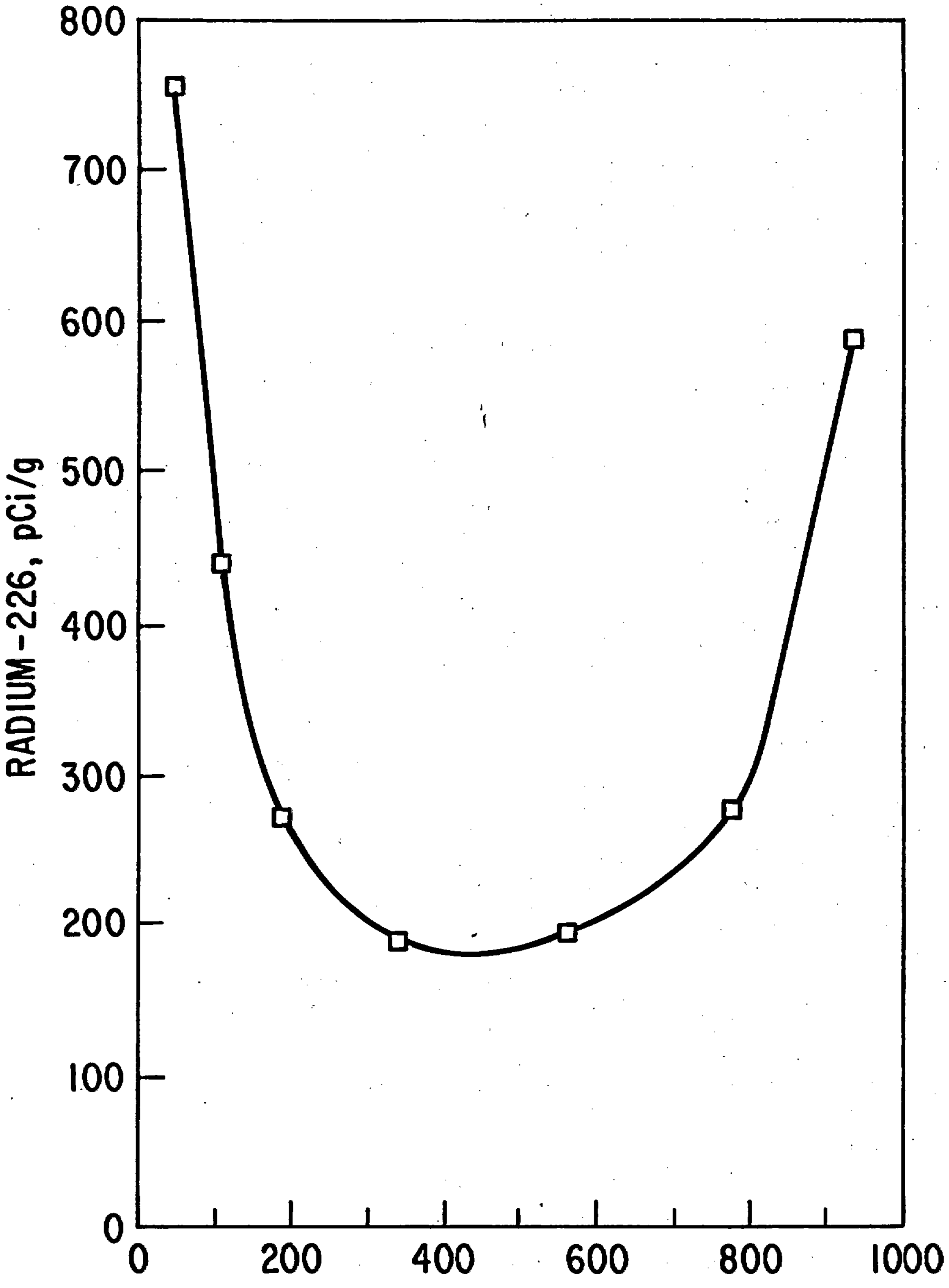

Fig. G-1.2. Specific Activity of Radium as a Function of Particle Size of Composite Acid-Leached Tailings with a Mean Activity of 365 pCi Ra-226/g. (The increase in activity for sizes larger than 450 µm may suggest aggregation of slimes to form larger sizes. Sizes were measured without breaking the aggregates.)

2. YELLOWCAKE DRYING AND PACKAGING

The second important composite source of radioactive emission from the mill occurs at the end of the ore processing line--the yellowcake drying and packaging operation. Although often referred to simply as U_3O_8 the yellowcake product from an acid leaching plant is a mixture of chemical complexes: diuranates, hydrated oxides, basic uranyl sulfate, and other ions.[14] The uranium (U_3O_8) content of yellowcake is assumed to be 90% by weight. After extraction, precipitation, and centrifugation, the uranium concentrate is dried. A variety of equipment is used for this purpose. Steam dryers provide relatively low temperatures in the 120-175°C range while, at the other extreme, multiple-hearth roasters operate up to 700°C.[14] The chemical composition of the final product is determined to a large extent by the drying temperature. Typically, the uranium content of the yellowcake when expressed as the equivalent amount of U_3O_8 lies in the range of 85-95% by weight.

Air flowing through the dryer and the dryer off-gas, as well as ventilation air from the packaging operation, is passed through dust-removing systems using water to remove the particles. The liquid collected from these dust control systems is recycled to the precipitating and thickening section of the mill. The efficiency of filtration is dependent on the airflow through the system and the particle size distribution. The particle size, in turn, is dependent on many factors, including equipment design and air flow rate and turbulence while the product is being dried.

Based on information provided by several mill operators, Sears, et al. estimated stack losses of yellowcake to be about 0.02% of the amount produced when dust collectors of 98% efficiency were in use.[10] More recent information from field studies supports the choice of a higher value for the model mill, but shows a wide range in the observed emission rates.[15] Even for a given stack, day-to-day variations in the hourly release rates by factors of 3 and 4 were seen. The difficulties of estimating annual average emissions are further compounded by the disparity among mills in the average number of hours per week the drying and packaging operations are conducted. The newly available stack emission data are reviewed in Appendix G-9 and it is concluded that a reasonable assumption for the model mill is that 0.1% of the uranium produced escapes as particulates to the atmosphere. This does not imply that yellowcake emission rates lower by factors of 10-100 are not achievable for, in fact, much lower rates have been demonstrated at specific mills.

Based on the upper range of values given in published reports from the early 1960s, Sears, et al. assumed that the thorium activity would be 5%, and radium, lead and polonium about 0.2% of the U-238 and U-234 activity in the yellowcake product.[10] These ratios have been applied in subsequent impact assessments for individual mills. More recent data[15-17] reviewed in Appendix G-9 suggest that these values may be overly conservative, especially in the case of Th-230. Based on these new field measurements, it has been assumed for the model mill that the thorium is 0.5% and the radium, lead and polonium each are 0.1% of the U-238 activity in the yellowcake. From this, the activity which escapes annually from the yellowcake stack is estimated to be about 150 mCi U-238 and U-234, 0.73 mCi Th-230, and 0.15 mCi of Ra-226, Pb-210 and Po-210. The calculation is based on the assumption that the model mill produces 520 MT of U_3O_8 each year (from Table 5.1) and proceeds as follows:

$$520 \text{ MT } U_3O_8/\text{yr} \times 0.001 \times 10^6 \text{ g/MT} \times 0.85 \text{ g U-nat/g } U_3O_8$$

$$\times\ 3.3 \times 10^{-7} \text{ Ci U-238/g U-nat} \times 10^3 \text{ mCi/Ci} = 1.46 \times 10^2 \text{ mCi U-238}$$

An equal number of millicuries of U-234 is released annually. This would be 1.4 kg U_3O_8 per day if averaged over 365 days per year.

The annual Th-230 emission therefore is:

$$1.46 \times 10^2 \text{ mCi/yr} \times 0.005 = 0.73 \text{ mCi/yr}$$

and the annual Ra-226, Pb-210, and Po-210 emission is:

$$1.46 \times 10^2 \text{ mCi/yr} \times 0.001 = 0.15 \text{ mCi/yr}$$

3. TAILINGS PILE

The third important source of radioactive emissions from the mill is the tailings area. Except for U-238, this is the predominant source of the radionuclides considered in this analysis. Tailings are composed of liquids and solids in proportion of about one metric ton of waste solution for each metric ton of solid tailings.[14] It is assumed that during the leaching process at the model mill, about 93% of the uranium is solubilized and 99% of the solubilized fraction is extracted; the fraction not extracted is discharged with the tailings waste solution but is partially recovered by recycling the solution. The overall uranium recovery efficiency is assumed to be 93%. While these values are typical of current practice, it should be noted that solubilization, extraction, and recycle recovery are processes whose efficiencies are determined by factors specific for each mill. For example, in order to increase daily product yield, a reduced extraction efficiency (shorter leach duration) and higher rate of ore throughput may be adopted.[14]

The solid tailings contain more than 60% of the total long-lived radioactivity originally present in the ore, including about 7% of the uranium, and essentially all of the Th-230, Ra-226, Pb-210, and Po-210.[18] The radioactivity content of slime solids is larger than that of the sand.[19,20] From the preliminary data presented in Figure G-1.2,[19] the increase in specific activity for particle sizes below 400 μm is clear. The amount of material in the slime fraction depends on the mill process and ranges from 20% to 40%. The relative amounts of slimes and sands on the surface of a tailings pile depends not only on the amount of each fraction in the process waste stream, but also on the procedure used to distribute the tailings on the pile and the time they have been subject to weathering and erosion. This is evident from the data plotted in Figure G-1.3, which is based on the same recent field study as the data shown in Figure G-1.2.[19] For the radiological assessment described in Chapter 6, the dry area of the tailings pond is considered to be a source of airborne particulates and radon.

3.1 Particulates

The mechanism of movement of tailings particles by wind is similar to the movement of soil and is dependent on wind velocity, physical properties of the tailings and the nature of the tailings surface.[1,21] Wind forces can generate three basic modes of particle movement: surface creep, saltation, and airborne suspension. Surface creep involves particles ranging in size from 500 to 1000 μm. These particles are rolled along the surface by the push of strong winds and by exchange of momentum after impact with smaller particles in saltation. Saltation consists of individual particles jumping and lurching within a few centimeters of the ground. Particles that saltate are from 100 to 500 μm in size, depending on shape and density, and are quickly brought back to the ground by the gravitational force. Particles smaller than 100 μm may have a velocity of fall lower than the upward velocity of the turbulent wind. Such particles are carried through the atmosphere for long periods and to great distances from their original location. The mechanism by which fine particles are lifted off the ground is different from that of saltation. It has been observed that samples of soil composed only of fine dust particles may be extremely resistant to erosion by wind,[22] but in mixtures with coarser grains these particles moved readily. It was concluded that suspension of fine dust in air may be primarily the result of movement of grains in saltation.

The particulate source term which represents the dust release from the dry tailings area of the model mill is calculated following the method and procedures outlined below.[23]

The wind velocity profile near the surface can be described by the general equation:[1]

$$U_z = U^*\left[2.5 \ln (z/z_0)\right] \tag{1}$$

where U^* = shear velocity,

$= \sqrt{\frac{\tau}{\rho}}$ where τ is the surface shear stress and ρ the density of air

z = height above surface, 1 meter

U_z = wind velocity at height z,

z_0 = surface roughness height,

= height at which $U_z = 0$, 0.01 meter.

When the wind above the surface exceeds a certain threshold velocity, particle saltation begins. The initiation of particle movement has been investigated by Bagnold, who expressed the threshold value of the shear velocity, U_t^*, as follows:[1]

$$U_t^* = A\sqrt{\frac{\sigma-\rho}{\rho}\, gd} \tag{2}$$

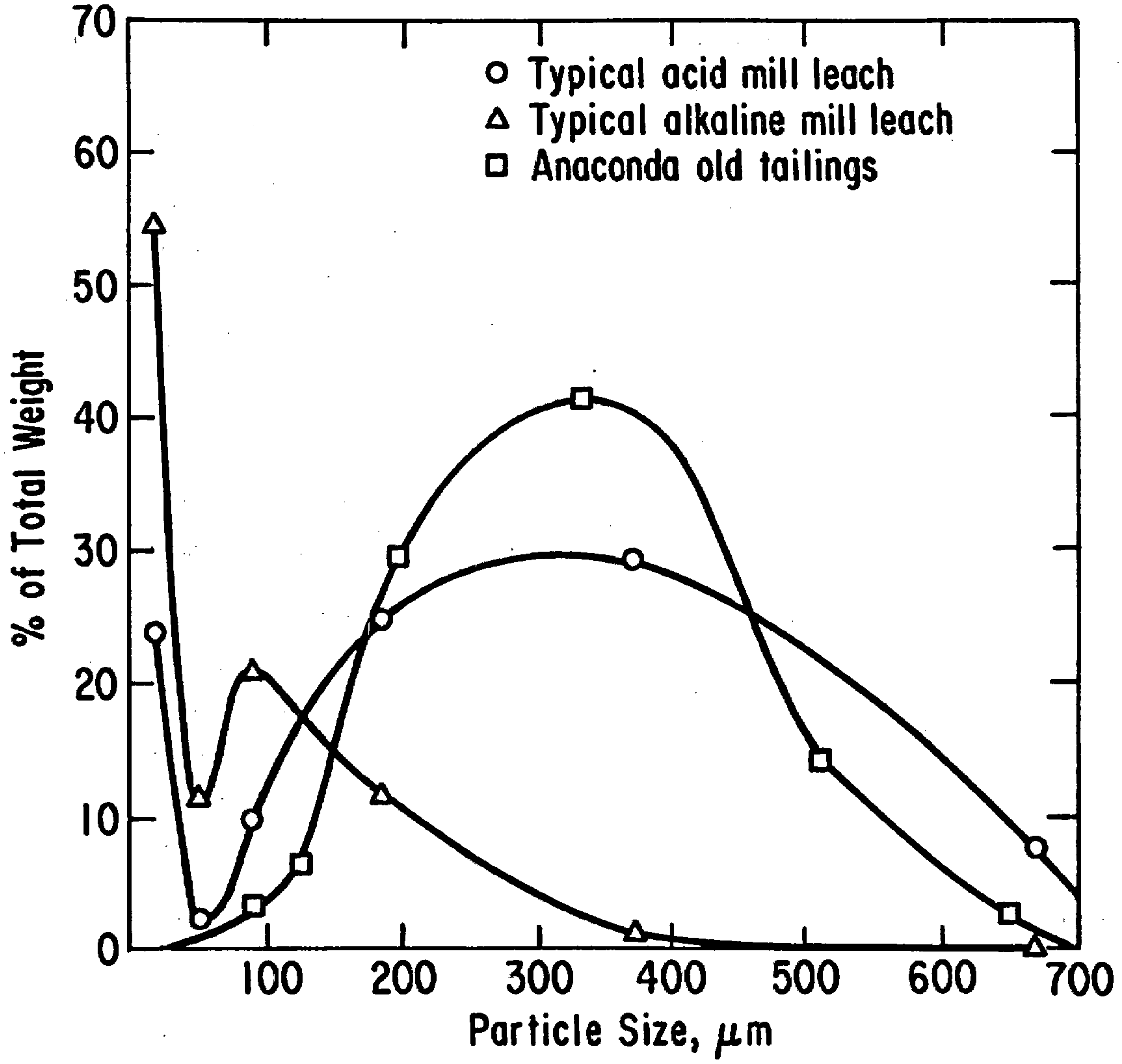

Fig. G-1.3. Comparison of Tailings Particle Size Distribution from Acid and Alkaline Leach Processes.

where σ = density of the grain, 2.4 g/cm^3,
ρ = density of air, 1.20×10^{-3} g/cm^3 (at 20° C),
g = gravitational constant, cm/s^2,
d = average diameter of the grain, 0.03 cm (300 μm),
A = dimensionless coefficient, the value of which in air for grains above 100 μm in diameter was found to be about 0.1.[1]

The influence of moisture in the sand on the threshold velocity for grain movement has been investigated by Belly.[2] Based on his study, Equation 2 may be modified as follows:

$$U_t^* = A\sqrt{\frac{\sigma-\rho}{\rho}\,gd}\,(1.8 + 0.6\log_{10} W) \qquad (3)$$

where W is the water content expressed in percent by weight. In this analysis the moisture content of dry tailings is assumed to be 0.1%.

The rate of horizontal particle movement by the saltation process, q, in mass per unit width and unit time was found by Bagnold to vary directly as the cube of the surface shear velocity,[1]

$$q = C_h U^{*3} \qquad (4)$$

where C_h is a constant dependent on the soil and surface conditions.

A modified relationship proposed by Lettan and reported by Gillette for the horizontal flux was observed for various soil types under similar erosion conditions.[24] This modification of Equation 4 is given by:

$$q = CU^{*2}\,(U^* - U_t^*),\ \text{and } q = 0 \text{ for } U^* \leq U_t^* \qquad (5)$$

where the shear velocities U^* and U_t^* have units of cm/s, the horizontal flux q has units of g/cm-s, and C equals 10^{-6} g-s^2/cm^4.

The wind pickup of fine particles (diameter, $d \leq 20$ μm) from soil surface has been investigated by Gillette.[24] He found that the vertical flux, expressed in mass per unit area and unit time, V_{20}, obeyed the empirical formula:

$$V_{20} = C_v\left[U^*/U_t^*\right]^{\gamma} \qquad (6)$$

where the coefficient of proportionality C_v is about 2×10^{-10}, and γ is a constant dependent on the fraction of fine particulates in the soil.

Since vertical fluxes are always associated with horizontal fluxes, an assumption was made that for wind-eroding surfaces, V_{20} is directly proportional to γ. Travis derived the following relationship:[25]

$$V_{20} = q\left\{\frac{C_v}{U_t^{*3}\,C_h}\right\}\left\{\frac{U^*}{U_t^*}\right\}^{\gamma-3} \qquad (7)$$

where γ is greater than three and increases as the number of suspendible particles per unit mass increases.

A linear curve fitting by Travis of Gillette's experimental field data for γ as a function of the particle mass percentage less than 20 μm in diameter, p, yielded the expression:

$$\gamma = \frac{p}{3} + 3 \qquad (8)$$

Since the vertical dust flux must approach zero as the suspended particle mass percentage, p, also approaches zero, Equation 7 was modified as follows:

$$V_{20} = q\left[\frac{C_v}{U_t^{*3}\ C_h}\right]\left[\left(\frac{U^*}{U_t^*}\right)^{p/3} -1\right] \qquad (9)$$

The constants C_v and C_h are approximately 2×10^{-10} and 10^{-6} respectively.[24]

For particulate material of diameter, d, between 0 µm and 100 µm, the total vertical flux for a radionuclide, i, in terms of radioactivity, V_i, is estimated using the following equation:

$$V_i = \frac{V_{20} \cdot I_{20}}{F_{20}} \qquad (10)$$

where I_{20} = specific activity of radionuclide "i" in tailings with a diameter less than 20µm.

F_{20} = activity fraction of suspended particulates that are less than 20 µm in diameter.

The parameters used for estimation of particulate emission from the tailings are as follows:

Surface roughness height , z_0 = 1 cm

Density of tailings grains, σ = 2.4 g/cm^3

Average grain diameter, d = 300 µm

Percent of tailings mass that is smaller than 20 µm, p = 3.0

Specific activity of radionuclide i in tailings with particle size less than 20 µm in diameter, I_{20}:

280 x 0.07 x 2.4 = 47.0 pCi/g (for U-238 and U-234)
280 x 2.4 = 672 pCi/g (for Th-230, Ra-226, Pb-210, and Po-210)

Dry tailings water content, W = 0.1%
Activity fraction of suspended particulates less than 20µm in diameter, F_{20} = 0.4.

The choice of 0.4 as the value of F_{20} is somewhat arbitrary, but is consistent with data presented in Reference 20 showing that about 80% of the activity of acid-leach tailings (as they occur on the ground, not suspended) is associated with particles less than 400 mesh (nominally 38 µm) in size. It also is consistent with the assumed particle size distribution on which the calculations of inhalation dose are based. As described in Appendix G-5, 30% of the radioactivity is assumed to be carried by tailings particles of 5 µm in diameter, while the remaining 70% of the activity is associated with 35-µm particles.

The radioactivity of radionuclide "i" released from the tailings surface per year, E_i, is dependent on the wind speeds, their frequencies of occurrence, and the total dry tailings area:

$$E_i = A\sum_w f_w\ V_i(w) \qquad (11)$$

where f_w = frequency of wind speed w,

A = total dry tailings area, 50 ha,

$V_i(w)$ = vertical flux of radioactivity for radionuclide i and wind speed w.

For example, the vertical activity flux, $V_{Ra\text{-}226}(10)$, produced by a wind speed of 10 mph measured at 1 m above the tailings surface may be calculated by using the above equations as follows:

From Eq. (1), the shear velocity is:

$$U^* = \frac{10 \text{ mph} \times 44.7 \text{ (cm/s)/mph}}{2.5 \ln(100 \text{ cm}/1 \text{ cm})} = 39 \text{ cm/s}$$

From Eq. (3), the threshold shear velocity necessary for saltation is:

$$U_t^* = 0.1\sqrt{\frac{2.4 - 1.20 \times 10^{-3}}{1.20 \times 10^{-3}} \times 980 \times 0.03}\ (1.8 + 0.6 \log_{10} 0.1) = 29 \text{ cm/s.}$$

From Eq. (5), the saltation rate is:

$$q = 10^{-6} \times (39)^2\ (39 - 29) = 1.5 \times 10^{-2} \text{ g/cm-s.}$$

From Eq. (9), the vertical flux for particulates with size less than 20 μm in diameter is:

$$V_{20} = 1.5 \times 10\text{-}2 \left[\frac{2 \times 10^{-10}}{29^3 \times 10^{-6}}\right]\left[\frac{39}{29} - 1\right] = 4.3 \times 10^{-11} \text{ g/cm}^2\text{-s,}$$

and from Eq. (10), the vertical activity flux for Ra-226 is:

$$V_{Ra\text{-}226}(10) = \frac{4.3 \times 10^{-11} \text{ g/cm}^2\text{-s} \times 672 \text{ pCi/g}}{0.4} = 7.2 \times 10^{-8} \text{ pCi/cm}^2\text{-s.}$$

The annual activity emissions from tailings, using the meteorological data given below in Table G-2.2, are calculated to be 8.7 mCi for U-238 and U-234 and 124 mCi for Th-230, Ra-226, Pb-210, and Po-210. The mass flux of particles under 100 μm in diameter from the tailings surface corresponding to this release of activity is 370 g/m²-year, or 185 MT/year from 50 ha.

3.2 Radon

The rate of radon exhalation, or flux, at the interface between a tailings pile and the atmosphere is dependent on (1) the rate of generation of radon from the parent radium, (2) the concentration of radon in the soil pore space, (3) diffusion through the pore spaces, and (4) transport phenomena.

The rate of radon generation is dependent on the concentration of radium [Ra] in the tailings, which is not constant through vertical and horizontal profiles because of variations in the quality of the ore processed through the years. Also, the differential settling of tailing solids after discharge to the pond results in spatial fractionation, the larger tailing grains being deposited closer to the point of discharge. Much of the radium activity in the tailings is associated with the finer grains which are washed to the lower areas and become buried at greater depth than the larger grains.[19]

The recoil energy of the radon ion after formation is about 0.1 MeV, and it has a track length of about 0.03 μm in the tailings solids and 60 μm in air.[26] The fraction of radon ions that recoil into pore space is dependent on the specific internal volume (ratio of internal pore surface to bulk volume) and tortuosity, i.e., average length of the flow path through the porous medium. If the path length is small, the recoiling radon will deposit on other grains and will not escape. The fraction of the radon generated by Ra-226 decay that escapes from mineral grains is commonly called the emanating power (ε). Values ranging from 0.01 to 0.91 have been reported for uranium ores.[13] The observed emanating power depends on many factors, such as the mineralogy, porosity, particle size distribution, and moisture content. As the ore is processed through the mill, changes occur which may influence the emanating power of the waste tailings. For "typical" tailings a value of approximately 0.2 has been given.[27] A series of measurements on dry, composite samples from the Vitro site yielded an emanating power of 0.20.[28] More recently, 15 samples from four different mining areas were found to range from 0.06 to 0.31, with an average emanating power of 0.15.[29] For this study an average value of 0.20 has been assumed. Therefore, the quantity of radon generated per unit volume of tailings and available for exhalation is proportional to [Ra]ερ where ρ is the bulk density of the tailings. The concentration, C, of radon (in picocuries/cm³) accumulated in the pore space is given by [Ra]ερ/P, where P is the porosity or void fraction, i.e., the fraction of the total volume that is not occupied by solid tailings particles (frequently identified by the symbol v in the literature). Values for porosity in the range of 30-40% have been reported.[10]

According to Fick's Law, the radon flux per unit area of tailings, J, is related to both P and the radon concentration per unit volume of void space, C, by means of an effective diffusion constant, k. The product kP is often called the effective bulk diffusion coefficient, D.

$$J = - D \frac{\partial C}{\partial x} \qquad (12)$$

where x represents distance in the direction in which the radon is diffusing.

If the radon flux, J, is expressed per unit area of open pores or voids, rather than in terms of total gross or geometric area, then the effective bulk diffusion coefficient, D, should be replaced in Eq. (12) by the larger effective diffusion constant, k. Values of the latter parameter often are quoted in the literature (for example, see Ref.10, Table 9.29) and often are identified as D_e/v, i.e., the bulk diffusion coefficient (D in this statement) divided by the porosity (P in this statement). In his latest review, Tanner refers to the parameter "D" (here labelled "bulk" diffusion coefficient) as the "true" diffusion coefficient, while k is called the "effective" diffusion coefficient.[30]

In addition to diffusion, convective transport of radon as a result of aeration of the soil or tailings contributes to radon exhalation. Meteorological parameters, including surface wind velocity, barometric pressure, and soil and air temperatures, have pronounced effects on radon transport. The field-measured bulk diffusion coefficient includes the effects of all these parameters on radon exhalation, with the result that diffusion can be separated from transport phenomena only with great difficulty. The exhalation rate and apparent bulk diffusion coefficient are strongly influenced by the moisture content of tailings.[29] Water exhibits a very small diffusion coefficient (about 10^{-5} cm^2/s)[26] and effectively reduces the rate of radon emission from wet tailings. The decrease in moisture content as tailings dry out results in an increasing rate of radon escape, approaching an asymptotic value as equilibrium between moisture in the tailings and rainfall is established.

The axial radon concentration and flux within multiple layers of tailings and cover materials may be calculated using general diffusion theory. The general one-dimensional diffusion equation at a particular point in tailings or covers is:

$$\frac{\partial C}{\partial t} = \frac{D}{P} \frac{\partial C}{\partial x^2} - C\lambda + \beta \qquad (13)$$

where C = the radon concentration (pCi/cm^3 of pore space)

D = the effective bulk diffusion coefficient (cm^2/s)

λ = radon decay constant ($2.1 \times 10^{-6}/s$)

β = radon source ($pCi/s\text{-}cm^3$ of pore space)

t = time (s)

x = axial distance (cm)

P = void fraction or porosity.

The radon source term, β, can be expressed as:

$$\beta = \lambda \left(\frac{\varepsilon}{P} \times [Ra] \times \rho\right) \qquad (14)$$

where ε = emanating power, 0.2

[Ra] = radium-226 concentration (pCi/gm)

ρ = tailings density ($1.6\ gm/cm^3$)

Assuming steady state, Eq. (13) can be written as:

$$- \frac{d}{dx}\left(\frac{D}{P} \cdot \frac{dC}{dx}\right) + \lambda C = \beta \qquad (15)$$

Equations (12) and (15) may be solved numerically for the radon flux J if the above parameters are known. The problem is simplified if the radium distribution is homogeneous and the tailings are effectively of infinite thickness (greater than 3-4 meters in depth). In this simple case, the radon flux in $pCi/m^2\text{-}s$ is given by the equation:

$$J_\infty = [Ra]\varepsilon\rho(\lambda D/P)^{\frac{1}{2}} \times 10^4 \qquad (16)$$

The choice of a representative value for D/P (or k) is critical in the estimation of a typical rate of radon release from uncovered tailings. As noted above, the amount of moisture in the tailings has a strong influence on the effective bulk diffusion coefficient. Preliminary data based on laboratory measurements suggest an experimental relationship such that 3% additional moisture in the tailings will reduce D/P by one-half.[29] Haywood et al.[31] have calculated the specific flux of radon (flux per pCi Ra-226 per gram of tailings) as a function of tailings depth, using values from Tanner[26] for the diffusion constant, k, of sands with different moisture content. Their values for infinitely thick piles range from approximately 0.35 pCi Rn/m^2-s per pCi Ra/g for wet tailings, to 0.65 for moist, to 1.2 for dry. The earlier review article by Tanner lists effective diffusion constants, k, ranging from 5.4×10^{-2} cm^2/s for sand with 4% moisture to 2.2×10^{-6} for mud with 85% moisture. Schiager suggests a value of 5×10^{-2} cm^2/s being typical of tailings and soil.[27] In the analysis of the model mill, a specific flux of 1.0 pCi Rn-222/m^2-s per pCi Ra-226/g tailings was assumed throughout. This implies a value of 4.7×10^{-2} cm^2/s for k = D/P in Eq. (16).

With the Ra-226 uniformly distributed throughout the tailings at a concentration of 280 pCi/g (this is the concentration assumed for the ore, and 99.9% of this radium remains in the tailings after extraction of the uranium), the annual emission from a bare pile having a dry area of 50 hectares is:

$$1.0\ (\text{pCi Rn-222/m}^2\text{-s})/(\text{pCi Ra-226/g tailings}) \times 280\ \text{pCi/g} \times 50\ \text{ha} \times 10^4\ \text{m}^2/\text{ha}$$

$$\times\ 3.165 \times 10^7\ \text{s/yr} \times 10^{-12}\ \text{Ci/pCi} = 4.43 \times 10^3\ \text{Ci Rn-222/yr.}$$

4. Radon from Dispersed Ore and Tailings

During operation of the model mill radium-bearing ore and tailings dusts will be released and will settle onto the ground surfaces around the mill site. The radium that settles out will continue to undergo radioactive decay to produce a secondary source of radon gas. The rate of release of radium from all sources is about 0.12 Ci/yr and comes almost all from dusting of exposed tailings surfaces. During 15 years of operation the environmental inventory of dispersed radium will reach about 1.8 curies. Each curie of dispersed radium will generate 66.2 Ci/yr of radon, about 20 percent of which will emanate out of the dust particles carrying the radium.[13] If all of the emanated radon gas diffuses into the atmosphere, this secondary radon source will amount to about 24 Ci/yr after 15 years of operation.

The estimated radium release rate from exposed tailings is based on the total dusting rate for particles less than 100 µm. Such particles are considered suspendible, and are subject to air-borne transport for sufficient distances to affect off-site locations. Particle sizes greater than 100 µm are generally not treated because they do not suspend and must be transported by mechanical processes of saltation or creep. These processes would not be expected to result in offsite contamination at appreciable distances but may account for as much as 50 percent of the total radium exiting the tailings impoundment. This would effectively double the total source of radon from dispersed radium dusts. Therefore, the secondary radon source after 15 years of operation is estimated to amount to about 48 Ci/yr.

This source would increase during the 5-year period required for drying and reclamation of the tailings impoundment, as tailings dusting continues and the amount of dispersed radium increases. During this 5-year period the dry tailings surface area is assumed to increase linearly from 50 ha to 80 ha; an additional 1.56 curies of radium (accounting for all particle sizes) would be released bringing the total inventory of dispersed radium from 3.6 curies to about 5.2 curies. This would increase the secondary radon source from 48 Ci/yr to about 69 Ci/yr.

After reclamation, the secondary radon source would continually diminish with time as the radium-bearing dusts mix deeper and deeper with natural soils, or are washed away into the oceans. It is estimated that the secondary radon source would decrease with an effective environmental half-life of approximately 50 years. Also, site cleanup during decommissioning would reduce this source of radon. A factor of two reduction is estimated on the basis of site cleanup in accordance with the criteria described in Appendix J. Post-reclamation secondary source radon releases are estimated, therefore, to have an initial value of about 35 Ci/yr, and to decrease by a factor of 2 every 50 years thereafter.

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APPENDIX G-2. AIR DISPERSION, PLUME DEPLETION, AND RADON DAUGHTER INGROWTH

1. AIR DISPERSION

Continuous dispersion models describing spatial and temporal variations in the distribution of radioactive concentrations in plumes have been based on the Fickian classical differential equation of diffusion. Air dispersion is calculated by the staff using the same models, data, and assumptions as documented more fully in Reference 1, using a sector-averaged Gaussian diffusion equation corrected for dry deposition, rainwash, and radioactive decay. The ground-level concentration $\chi(x)$ of a radionuclide in air at distance x, downwind from a point source at x=0 is given by:

$$\chi(x) = \sqrt{\frac{2}{\pi}}\,\frac{Q}{\sigma_z U}\,\exp\left\{-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right\}\frac{n}{2\pi x} \qquad (1)$$

where: Q = effective emission rate from the source,

σ_z = standard deviation of the plume concentration distribution in the vertical direction,

U = mean wind speed,

h = effective stack height, and

n = number of sectors (equal to 16).

Wind speeds in each of 16 directions or sectors are grouped in six classes (0-3, 4-6, 7-10, 11-16, 17-21, and >21 knots). The atmospheric stabilities are classified into six categories (S = 1, 2, 3, 4, 5, and 6) in order of increasing stability. The six stability categories are based on criteria stated by Pasquill.[2] The values of σ_z (x,S) used are those of Briggs.[3] For computational purposes, these were represented by the following formula:[3,4]

$$\sigma_z = (ax)(1+bx)^c \qquad (2)$$

where a, b, and c are constants for each stability class, as shown in Table G-2.1. Equation 1 is unreliable for small values of x, hence only values of $x \geq 100$ meters are used in calculating σ_z.

It is assumed that the vertical distribution of the radionuclide concentration is Gaussian and centered at the effective release height (5 m for the ore pad, feed and grinding; 15 m for yellowcake drying and packaging; ground level for the tailings pile). The distribution across each sector in the perpendicular horizontal direction is assumed to be uniform.

Table G-2.1 Stability Class Parameters for Equation 2

S	Pasquill Type Stability Class	a	b	c
1	A	0.2	0	0
2	B	0.12	0	0
3	C	0.08	0.0002	-0.5
4	D	0.06	0.0015	-0.5
5	E	0.03	0.0003	-1
6	F	0.016	0.0003	-1

Wind speed and frequency are specified in 16 directions ($n = 16$), corresponding to 22.5-degree sectors. The standard deviation of the vertical distribution of concentration σ_z increases in the downwind direction to a distance of x_L, at which $\sigma_z = 0.47L$, where L is the vertical distance from the ground to the base of the stable atmosphere layer (mixing layer height). At the base of the stable layer, the concentrations of the radionuclides will be about one-tenth of that at the plume centerline. For distances less than x_L, the vertical distribution is assumed to be Gaussian and to follow Equation (2). At distances between x_L and $2x_L$, the trapping effect of the elevated stable layer increases and, except for the stable classes E and F, the concentration χ is determined by linear interpolation between the value from Equation (1) at x_L and the uniform mixing value from Equation (3) at $2xL$:

$$\chi(x) = \frac{Q}{LU(2\pi x/n)} \tag{3}$$

For distance $x > 2x_L$, uniform mixing below tne base of the stable layer is assumed and the average concentration is calculated from Equation (3). The mixing layer height L varies greatly with the season, day to day, and also diurnally. Since it is impractical to account for all these variations, only the annual average height for the mixing layer L is used. L has been estimated from:

$$L = \frac{2L_{AM}\ L_{PM}}{L_{AM} + L_{PM}} \tag{4}$$

where L_{AM} and L_{PM} are the mean annual morning and afternoon mixing heights, to be about 850 meters for the model region. The concept of a mixing height is not employed for class E and F stabilities.

The discontinuities at sector boundaries, due to the sector-average approximation, are corrected by a linear interpolation of concentrations between sector centerlines using:

$$\chi(x) = \frac{C - y_1}{C}\ \chi(x,\theta_1) + \frac{C - Y_2}{C}\ \chi(x,\theta_2) \tag{5}$$

where C is defined as the sector width at the receptor location x, $C = \frac{2\pi x}{n}$ and y_1 and y_2 are the crosswind distances between the receptor and the sector centerlines of the sector containing the receptor $\theta = \theta_1$ and the nearest adjacent sector $\theta = \theta_2$, respectively.

Concentration of the radionuclide $\chi(x,D,W,S,Q)$ at a distance x from a source Q and direction D, wind speed W, and stability S is computed from the appropriate equations. The annual average concentration χ from the source Q is calculated by summing each concentration $\chi(x,D,W,S,Q)$ weighted by the frequency $f(D,W,S)$ for the particular wind speed and stability class:

$$\chi(x,Q) = \sum_{D} \sum_{W} \sum_{X} f(D,W,S)\ \chi(x,D,W,S,Q) \tag{6}$$

The total annual average concentration from all sources is calculated from Equation (6) by summing the contributions from each source. The joint frequency distribution of wind speed, direction, and stability class employed to characterize the model region is presented in Table G-2.2.

For area sources, the model converts the area into equivalent squares of width "d." It is assumed that a "virtual point source" is located at a distance of $d/2 \cot \Delta\theta/2$ upwind from the center of the source area, where $\Delta\theta$ is the 22.5-degree sector used to subtend the area width. For near receptors which cannot "see" the whole source area within a 22.5-degree sector, the source emission rate is multiplied by a correction factor. The correction factor is the ratio of that portion of the source area lying within a 22.5-degree sector located upwind from the receptor to the total source area.

Table G-2.2 Joint Percent Frequency of Annual Average Wind Speed, Direction and Stability Class for Model Mill Region (Page 1 of 2)

Speed*	Direction From Which Wind Blows																
meters/second	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
STABILITY CLASS A																	
0.0-1.5	0.06	0.10	0.08	0.05	0.03	0.02	0.02	0.03	0.08	0.07	0.08	0.13	0.15	0.16	0.08	0.06	1.20
1.6-3.2	0.05	0.07	0.06	0.03	0.02	0.01	0.01	0.02	0.06	0.05	0.06	0.09	0.10	0.11	0.06	0.02	0.82
3.3-5.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.2-8.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.3-10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALL	0.11	0.17	0.14	0.08	0.05	0.03	0.03	0.05	0.14	0.12	0.14	0.22	0.25	0.27	0.14	0.08	2.02
STABILITY CLASS B																	
0.0-1.5	0.17	0.28	0.27	0.15	0.22	0.04	0.10	0.00	0.18	0.33	0.41	0.85	0.59	0.33	0.22	0.24	4.38
1.6-3.2	0.09	0.15	0.13	0.08	0.11	0.02	0.03	0.00	0.09	0.17	0.22	0.45	0.31	0.17	0.12	0.13	2.27
3.3-5.1	0.10	0.06	0.02	0.08	0.06	0.01	0.01	0.02	0.07	0.14	0.17	0.22	0.20	0.09	0.07	0.02	1.34
5.2-8.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.3-10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALL	0.36	0.49	0.42	0.31	0.39	0.07	0.14	0.02	0.34	0.64	0.80	1.52	1.10	0.59	0.41	0.39	7.99
STABILITY CLASS C																	
0.0-1.5	0.08	0.11	0.14	0.11	0.06	0.00	0.02	0.02	0.12	0.10	0.20	0.21	0.26	0.10	0.06	0.05	1.64
1.6-3.2	0.20	0.26	0.34	0.26	0.14	0.01	0.06	0.05	0.29	0.23	0.45	0.52	0.62	0.25	0.14	0.11	3.93
3.3-5.1	0.24	0.24	0.14	0.30	0.23	0.07	0.05	0.06	0.25	0.52	0.74	0.85	0.71	0.34	0.10	0.21	5.05
5.2-8.2	0.03	0.03	0.05	0.00	0.01	0.00	0.01	0.00	0.06	0.13	0.43	0.31	0.23	0.10	0.05	0.01	1.45
8.3-10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.09	0.21	0.05	0.00	0.00	0.00	0.43
>10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.04
ALL	0.55	0.64	0.67	0.67	0.44	0.08	0.14	0.13	0.72	1.07	1.93	2.10	1.88	0.79	0.35	0.38	12.54

Table G-2.2 Joint Percent Frequency of Annual Average Wind Speed, Direction and Stability Class for Model Mill Region (Page 2 of 2)

Speed* meters/second	Direction From Which Wind Blows																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
STABILITY CLASS D																	
0.0-1.5	0.16	0.13	0.11	0.11	0.06	0.02	0.09	0.09	0.18	0.19	0.22	0.31	0.25	0.06	0.04	0.06	2.08
1.6-3.2	0.30	0.23	0.20	0.21	0.10	0.03	0.13	0.16	0.33	0.36	0.38	0.54	0.39	0.10	0.07	0.10	3.63
3.3-5.1	0.45	0.32	0.31	0.68	0.52	0.09	0.18	0.31	0.84	1.39	1.78	1.93	1.02	0.44	0.14	0.21	10.61
5.2-8.2	0.22	0.24	0.14	0.37	0.36	0.10	0.16	0.14	0.68	1.17	3.37	3.13	1.60	0.80	0.36	0.11	12.95
8.3-10.8	0.02	0.06	0.01	0.02	0.01	0.02	0.02	0.03	0.14	0.31	1.00	1.01	0.47	0.13	0.03	0.01	3.29
>10.8	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.07	0.13	0.21	0.02	0.00	0.00	0.00	0.48
ALL	1.15	0.99	0.77	1.39	1.05	0.27	0.59	0.73	2.19	3.49	6.88	7.13	3.75	1.53	0.64	0.49	33.04
STABILITY CLASS E																	
0.0-1.5	1.39	1.15	1.66	1.53	1.58	1.54	1.11	1.00	2.31	1.38	2.18	2.37	1.23	0.41	0.31	0.34	21.49
1.6-3.2	0.52	0.44	0.53	0.50	0.46	0.36	0.37	0.38	0.75	0.56	0.71	0.79	0.48	0.15	0.11	0.08	7.19
3.3-5.1	0.21	0.15	0.16	0.30	0.18	0.02	0.06	0.14	0.52	0.62	0.83	0.61	0.34	0.18	0.15	0.14	4.61
5.2-8.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.3-10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALL	2.12	1.74	2.35	2.33	2.22	1.92	1.54	1.52	3.58	2.56	3.72	3.77	2.05	0.74	0.57	0.56	33.29
STABILITY CLASS F																	
0.0-1.5	0.45	0.37	0.47	0.42	0.42	0.25	0.31	0.32	0.64	0.43	0.65	0.79	0.40	0.10	0.06	0.07	6.15
1.6-3.2	0.23	0.17	0.14	0.14	0.18	0.13	0.16	0.17	0.31	0.15	0.30	0.37	0.24	0.07	0.06	0.06	2.88
3.3-5.1	0.04	0.07	0.06	0.10	0.06	0.02	0.04	0.07	0.13	0.22	0.40	0.50	0.20	0.08	0.04	0.06	2.09
5.2-8.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.3-10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>10.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALL	0.72	0.61	0.67	0.66	0.66	0.40	0.51	0.56	1.08	0.80	1.35	1.66	0.84	0.25	0.16	0.19	11.12
ALL	5.01	4.64	5.02	5.44	4.81	2.77	2.95	3.01	8.05	8.68	14.82	16.40	9.87	4.17	2.27	2.09	100.0

*The six wind speed intervals listed correspond to the following average values used: 0.67056, 2.45872, 4.47040, 6.92912, 9.61136, 12.51712 meters/second, respectively.

2. PLUME DEPLETION

The concentration of radioactive materials in the atmosphere is depleted by the mechanisms of dry deposition, wet deposition, and radioactive decay. These depletion processes result in a reduction of the effective source strength at increasing distances from the emission point.

Deposition, as used in this context, includes the processes of gravitational settling, adsorption, particle interception, diffusion, chemical electrostatic effects, and rain wash. Total ground deposition is calculated from the deposition velocity, V_d, defined by Chamberlain as the ratio of the deposition rate $W(Ci/m^2\text{-sec})$ to the ground-level air concentration $\chi(Ci/m^3)$.[5] Thus, $V_d = W/\chi$. The physical processes which determine the deposition velocity are complex and not thoroughly understood, and depend on the material being deposited, the receptor surface, and the turbulence.

For particulates, it is assumed in the model that the material will have a settling or fall velocity given by Stoke's Law:

$$V_s = \frac{D^2 g \rho}{18\mu} \tag{7}$$

where V_s = settling or fall velocity,

D = diameter of the particle,

g = acceleration of gravity,

ρ = density of the particle, and

μ = atmospheric dynamic viscosity.

At fall velocities less than about 1 cm/sec, the vertical movement of the particle is dependent on larger vertical turbulent and mean air motion, and the effect of sedimentation is negligible. Where the sedimentation rate is significant (V_s = 1 to 100 cm/sec), the effect due to the resulting downward tilt of the plume centerline can be expressed by replacing its constant height, h, with a variable expression such that:

$$h(x) = h(0) - \frac{xV_s}{U};\ h(x) \geq 0 \tag{8}$$

where x is the distance from the source and U is the mean wind speed. The model uses a deposition velocity V_d = 0.01 m/sec for particulates with fall velocities, V_s, less than 0.01 m/sec.[6] The products of radon decay in air (Pb-210 and Po-210) are exceptions. They are assumed to have an aerodynamic diameter of 0.3 µm and to deposit with a V_d = 0.003 m/sec. For larger particles with fall velocities greater than 0.01 m/sec, the calculated fall velocity is assumed to be the deposition velocity.

The correction for plume depletion due to deposition is made by replacing the constant source term Q_0, at the source emission point, by a variable expression which includes V_d and appropriate meteorological parameters.[1] The integral expressions in the resulting equations are evaluated numerically.

3. RADON DAUGHTER INGROWTH

Radioactive decay during transport through the atmosphere is considered for short-lived radon ($T_{\frac{1}{2}}$ = 3.8 days). The transit time during which radioactive decay occurs can be approximated as the ratio of the distance traveled, x, to the wind speed, U, or t = x/U. The source strength as corrected for radioactive decay is:

$$Q(x) = Q_0 \exp\left(-\frac{\lambda_{Rn} x}{U}\right) \tag{9}$$

The ingrowth of radon daughter products is represented as follows:

$$\text{Rn} \xrightarrow{\lambda_{Rn}} \overset{\text{RaA}}{(\text{Po-218})} \xrightarrow{\lambda_{RaA}} \overset{\text{RaB}}{(\text{Pb-214})} \xrightarrow{\lambda_{RaB}} \overset{\text{RaC}}{(\text{Bi-214})} \xrightarrow{\lambda_{RaC}} \overset{\text{RaD}}{(\text{Pb-210})} \xrightarrow{\lambda_{RaD}} \overset{\text{RaE}}{(\text{Bi-210})} \xrightarrow{\lambda_{RaE}} \overset{\text{RaF}}{(\text{Po-210})} \xrightarrow{\lambda_{RaF}}$$

The activities of radon daughter products are found by solving the appropriate set of differential equations using standard methods. The very short-lived daughter of Bi-214, Po-214, is omitted above because it is not explicitly treated in the kinetic transport equations; it is assumed to be in equilibrium with Bi-214 for purposes of dose evaluation.

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APPENDIX G-3 CONCENTRATIONS IN ENVIRONMENTAL MEDIA

This section of Appendix G describes the models, equations, and data employed in the determination of radioactivity concentrations in the environmental media of interest. These are the concentrations used in the final computations of individual and population dose commitments and include concentrations on ground surfaces, total air concentrations, and concentrations in vegetation, meat, and milk.

1. GENERAL CALCULATIONAL PROCEDURES

Environmental media concentrations are computed as functions of the calculated annual average air concentrations resulting directly from mill releases (not including resuspended air concentrations) and the time duration that those direct air concentrations have existed. The direct air concentrations are computed as described earlier in Appendix G-2 and include the effects of depletion by deposition (for particulates) and ingrowth and decay during transit (for radon and daughters). Because of the halflives and relative abundances involved it is necessary to compute direct air concentrations explicitly only for certain specific radionuclide and particle size combinations; for other radionuclide-particle size combinations an assumption of secular equilibrium suffices. Table G-3.1 defines the characteristics of the particle size categories used in this analysis and indicates the radionuclide-particle size combinations for which direct air concentrations are explicitly computed.

Figure G-3.1 is a schematic diagram of the general calculational procedures used to compute the required environmental media concentrations from direct air concentrations. The first step involves treatment of the direct air concentrations to obtain ground concentrations and resuspended air concentrations. Resuspension of radioactive materials is not treated as a loss mechanism in the computation of ground concentrations and, therefore, ground concentrations are not assumed to be increased by deposition of resuspended activity.

Concentrations of resuspended particulates in air are added to direct air concentrations to obtain total air concentrations, which are then used to obtain total deposition rates. Total deposition rates and ground concentrations are used to compute concentrations in various categories of vegetation, including hay and forage (resuspension losses of activity deposited on vegetation are assumed to be accounted for by the application of a weathering half-life). Hay and forage concentrations are used to calculate radioactivity concentrations in meat and milk ingested by man.

2. GROUND CONCENTRATIONS

Ground radionuclide concentrations are computed from the calculated airborne particulate concentrations arising directly from mill emissions (not including air concentrations resulting from resuspension of previously deposited particulates). The phenomenon of resuspension is treated neither as a loss or a source of ground concentrations. Thus the ground concentration of radionuclide i depends directly on the direct deposition rate, which is given by the following relationship

$$D_{di} = \sum_{p} C_{adip} V_p \qquad (1)$$

where C_{adip} is the direct air concentration of isotope i in particle size p, pCi/m^3;

D_{di} is the resulting direct deposition rate of isotope i, pCi/m^2-sec; and

V_p is the deposition velocity of particles in particle size p, m/sec (see Table G-3.1).

The concentration of isotope i on a ground surface due to constant deposition at the rate D_{di} over time interval t is obtained from

$$C_{gi}(t) = D_{di} \left\{ \frac{1 - \exp\left[-(\lambda_i + \lambda_e)t\right]}{\lambda_i + \lambda_e} \right\} \qquad (2)$$

Table G-3.1 Particle Size Category Characteristics and Isotope-Particle Size Combinations for Which Direct Air Concentrations are Explicitly Computed

Particle Size Category (p)*	Diameter Range, μm	Particle Size Category Characteristics		
		Mean Diameter, μm	Density g/cm^3	Deposition Velocity, m/sec
p = 1	-	1.0	8.9	0.010
p = 2	-	1.0	2.4	0.010
p = 3	1 to 10	5.0	2.4	0.010
p = 4	10 to 80	35.0	2.4	0.0882
p = 5	-	-	-	0.003

Isotope-Particle Size Combinations for Which Direct Air Concentrations are Explicitly Computed**

i	Isotope (i)	Particle Size Category Index				
		p = 1	p = 2	p = 3	p = 4	p = 5
1	U-238	CE	CE	CE	CE	--
2	Th-234	se	se	se	se	--
3	Pa-234	se	se	se	se	--
4	U-234	se	se	se	se	--
5	Th-230	CE	CE	CE	CE	--
6	Ra-226	CE	CE	CE	CE	--
7	Rn-222***	se	se	se	se	--
8	Po-218	se	se	se	se	CE
9	Pb-214	se	se	se	se	CE
10	Bi-214	se	se	se	se	CE
11	Po-214	se	se	se	se	se
12	Pb-210	CE	CE	CE	CE	CE
13	Bi-210	se	se	se	se	CE
14	Po-210	se	se	se	se	CE

---

*In this analysis particle size groups are assigned to effluents as follows: p=1 for yellowcake dust; p=2 for fugitive ore dust; p=3 (30 percent) and p=4 (70 percent) for fugitive tailings dust; and p=5 for air ingrowth concentrations of Rn-222 particulate daughters.

**The entry "CE" denotes "calculated explicitly." The entry "se" denotes "secular equilibrium" in which case the direct air concentration of the indicated isotope, in the particular particle size category, is assumed to be identical to that of the first parent for which it is explicitly calculated.

***The direct air concentration of Rn-222 is also computed; Rn-222 is an inert gas and no particle size is assigned.

where $C_{gi}(t)$ is the surface ground concentration of isotope i at time t, pCi/m^2;

λ_e is the assumed rate constant for environmental loss, sec^{-1}.

t is the time interval over which deposition has occurred, sec;

λ_i is the radioactive decay constant* for isotope i, sec^{-1}; and

The environmental loss constant, λ_e, derives from an assumed half-life in soil, with respect to environmental availability, of 50 years. This parameter is designed to account for downward migration in soil and loss through chemical binding. It is assumed to apply to all isotopes subject to ground deposition.

Ground concentrations are computed explicitly only for U-238, Th-230, Ra-226, and Pb-210 (see Table G-3.1). For all other isotopes, the ground concentration is assumed equal to that of the next higher-up parent for which the ground concentration is calculated explicitly. For Pb-210, ingrowth from deposited Ra-226 can be significant. The concentration of Pb-210 on ground due to Ra-226 deposition is calculated using the standard Bateman formulation and assuming that Ra-226

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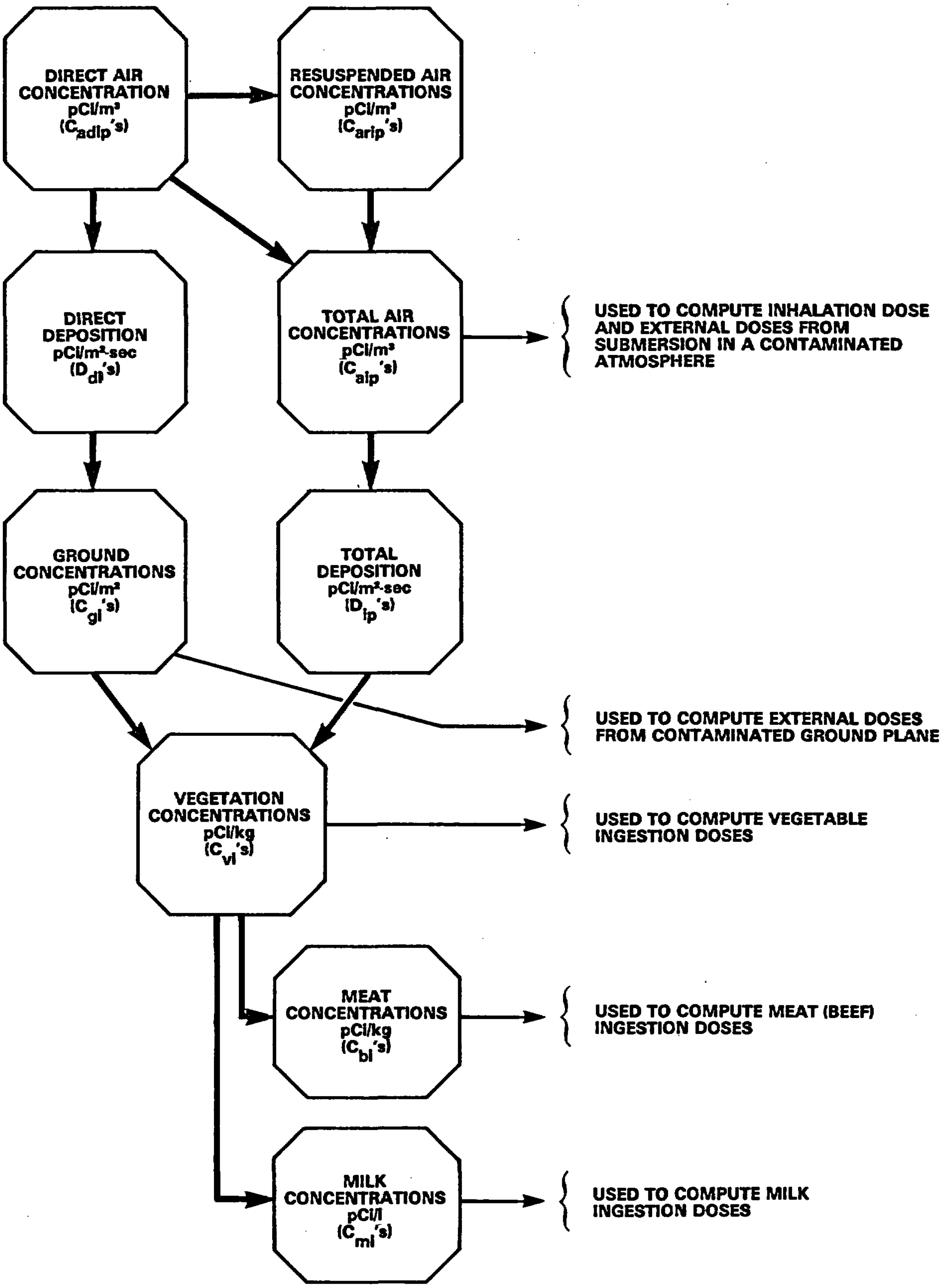
*Radiological decay constants employed by the staff are obtained from data given in Reference 1.

Figure G-31 Schematic Diagram of Information Flow and Use For Dose Calculations



decays directly to Pb-210. Using i = 6 for Ra-226 and i = 12 for Pb-210 (see Table G-3.1), the following equation obtains

$$C_{g12}\,(Pb \leftarrow Ra) = \frac{\lambda_{12}\, D_{d6}}{\lambda_6^*} \left\{ \frac{1 - e^{-\lambda_{12}^* t}}{\lambda_{12}^*} + \frac{e^{-\lambda_6^* t} - e^{-\lambda_{12}^* t}}{\lambda_6^* - \lambda_{12}^*} \right\} \tag{3}$$

where C_{g12} (Pb ← Ra) is the incremental Pb-210 ground concentration resulting from Ra-226 deposition, pCi/m²; and

λ_n^* is the effective rate constant for loss from ground concentrations and is equal to $\lambda_n + \lambda_e$, sec^{-1}.

3. TOTAL AIR CONCENTRATIONS

In order to compute total deposition rates onto vegetation, inhalation doses, and external doses from irradiation by airborne activity, total air concentrations are required. The total air concentration of each isotope at each location, as a function of particle size, is computed as the sum of the direct air concentration and the resuspended air concentration as follows

$$C_{aip}(t) = C_{adip} + C_{arip}(t) \tag{4}$$

where $C_{aip}(t)$ is the total air concentration of isotope i, particle size p, at time t, pCi/m³;

C_{adip} is the direct air concentration of isotope i, particle size p, (constant) pCi/m³; and

$C_{arip}(t)$ is the resuspended air concentration of isotope i, particle size p, at time t, pCi/m³.

The resuspended air concentration is computed using a time and particle size dependent resuspension factor, which, for deposits of age t years, is defined by

$$R_p(t) = (0.01/V_p)\ 10^{-5}\ e^{-\lambda_R t} \qquad \text{(for } t \leq 1.82 \text{ years)} \tag{5a}$$

$$\text{and} \quad R_p(t) = (0.01/V_p)\ 10^{-9} \qquad \text{(for } t > 1.82 \text{ years)} \tag{5b}$$

where $R_p(t)$ is the ratio of the resuspended air concentration to the ground concentration, for a ground concentration of age t years, of particle size p, m^{-1};

V_p is the deposition velocity of particle size p, m/sec;

λ_R is the assumed decay constant of the resuspension factor (equivalent to a 50-day half-life), 5.06 yr^{-1};

0.01 is the deposition velocity for the particle size for which the assumed initial and final values of the resuspension factor apply, m/sec;

10^{-5} is the initial value of the resuspension factor (for fresh deposits of particles with a deposition velocity of 0.01 m/sec), m^{-1};

10^{-9} is the terminal value of the resuspension factor (for particulates with a deposition velocity of 0.01 m/sec), m^{-1}; and

1.82 is the time required for the resuspension factor to decay from its initial value to its terminal value, yrs.

The basic formulation of the above expression for the resuspension factor, the initial and terminal values, and the assigned decay constant derive from experimental results of plutonium resuspension measurements (Ref. 2). The decrease with age of the resuspension factor primarily accounts for agglomeration with other, larger particles. The inverse relationship to deposition velocity physically accounts for decreased resuspendability of larger particles; mathematically, it eliminates mass balance problems for the 35 μm particle size. Based on this expression for the resuspension factor, the resuspended air concentration may be derived as

$$C_{arip}(t) = 0.01\ C_{adip}\ 10^{-5} \left\{ \frac{1 - \exp[-(\lambda_i^* + \lambda_R)(t-a)]}{(\lambda_i^* + \lambda_R)} \ldots \right.$$

$$\left. \ldots + 10^{-4}\ \delta(t)\ \frac{\exp[-\lambda_i^*(t-a)] - \exp(-\lambda_i^* t)}{\lambda_i^*} \right\} (3.156 \times 10^7) \qquad (6)$$

where

a is equal to $(t-1.82)$ if $t > 1.82$ and is equal to zero otherwise, yrs;

$\delta(t)$ is zero if $t \leq 1.82$ and is unity otherwise, dimensionless;

λ_i^* is the effective decay constant for isotope i on soil, yr^{-1};

0.01 is the deposition velocity for the particle size for which the initial resuspension factor value is 10^{-5}/m, m/sec; and

3.156×10^7 is sec/yr.

The above equation yields the resuspended air concentration of isotope i in particle size p due to deposition over time span t. Total air concentrations are computed using Equations 6 and 4 (in that order) for all particulates in particle sizes 1 through 4 (see Table G-3.1). Particulate daughters of Rn-222 (particle size 5 in Table G-3.1) are not depleted due to deposition losses and are therefore not assumed to resuspend.

4. CONCENTRATIONS IN VEGETATION

As illustrated in Figure G-3.1, vegetation concentrations are derived from ground concentrations and total deposition rates. Ground concentrations are used to determine vegetation concentrations resulting from root uptake of soil activity; total deposition rates are used to determine vegetation concentrations resulting from foliar retention of deposited activity. Total deposition rates are obtained by the following summation

$$D_i = \sum_p C_{aip}\ V_p \qquad (7)$$

where D_i is the total deposition rate, including deposition of resuspended air concentrations, pCi/m²-sec.

Concentrations of released particulate materials can be environmentally transferred to the edible portions of vegetables, or to hay or pasture grass consumed by animals. Five categories of vegetation are treated in this analysis: edible above ground vegetables, potatoes, other edible below ground vegetables, pasture grass, and hay. Vegetation concentrations are computed using the following equation

$$C_{vi} = D_i\ F_r\ E_v \left\{ \frac{1 - \exp(-\lambda_w t_v)}{Y_v \lambda_w} \right\} + C_{gi}\ \frac{B_{vi}}{P} \qquad (8)$$

where B_{vi} is the soil to plant transfer factor for isotope i, vegetation type v, dimensionless;

C_{vi} is the resulting concentration of isotope i, in vegetation v, pCi/kg;

E_v is the fraction of the foliar deposition reaching edible portions of vegetation v, dimensionless;

F_r is the fraction of the total deposition retained on plant surfaces, 0.2, dimensionless;

P is the assumed areal soil density for surface mixing, 240 kg/m²;

t_v is the assumed duration of exposure while growing for vegetation v, sec;

Y_v is the assumed yield density of vegetation v, kg/m^2; and

λ_w is the decay constant accounting for weathering losses (equivalent to a 14-day half-life), 6.73 x 10^{-7}/sec.

The value of E_v is assumed to be 1.0 for all above ground vegetation, and 0.1 for all below ground vegetables (Ref. 3). The value of t_v is taken to be 60 days, except for pasture grass where a value of 30 days is assumed. The yield density, Y_v, is taken to be 2.0 kg/m^2 except for pasture grass where a value of 0.75 kg/m^2 is applied. Values of the soil to plant transfer coefficients, B_{vi}, are provided in Table G-3.2. As with ground and air concentrations, vegetation concentrations are computed explicitly only for certain isotopes (U-238, Th-230, Ra-226, and Pb-210). Concentrations of other isotopes of concern for ingestion pathways are simply assumed to be identical to those of the first parent isotopes for which vegetation concentrations are explicitly computed.

Table G-3.2 Environmental Transfer Coefficients*

	U	Th	Ra	Pb
I. Plant/Soil (B_{vi}'s)				
a) Edible Above Ground:	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}
b) Potatoes:	2.5×10^{-3}	4.2×10^{-3}	3.0×10^{-3}	4.0×10^{-3}
c) Other Below Ground:	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}
d) Pasture Grass:	2.5×10^{-3}	4.2×10^{-3}	1.8×10^{-2}	2.8×10^{-2}
e) Stored Feed (Hay):	2.5×10^{-3}	4.2×10^{-3}	8.2×10^{-2}	3.6×10^{-2}
II. Beef/Feed (F_{bi}'s)				
pCi/kg per pCi/day:	3.4×10^{-4}	2.0×10^{-4}	5.1×10^{-4}	7.1×10^{-4}
III. Milk/Feed (F_{mi}'s)				
pCi/ℓ per pCi/day:	6.1×10^{-4}	5.0×10^{-6}	5.9×10^{-4}	1.2×10^{-4}

*Sources for this data include References 4-7.

5. CONCENTRATIONS IN MEAT AND MILK

Radioactive particulate materials can be deposited on hay or pasture grass which are eaten by meat animals which are in turn eaten by man. The equation used to estimate meat concentrations is

$$C_{bi} = Q\ F_{bi}\ (0.5\ C_{pgi} + 0.5\ C_{hi}) \tag{9}$$

where C_{bi} is the resulting average concentration of isotope i in meat, pCi/kg;

C_{hi} is the concentration of isotope i in hay (or other stored feed), pCi/kg;

C_{pgi} is the concentration of isotope i in pasture grass, pCi/kg;

F_{bi} is the feed to meat transfer factor for isotope i, pCi/kg per pCi/day ingested (see Table G-3.2);

Q is the assumed feed ingestion rate, 50 kg/day (Ref. 3); and

0.5 is the fraction of the annual feed requirement assumed to be satisfied by pasture grass or locally grown stored feed (hay or other), dimensionless.

The factor 0.5 appears twice in Eq. 9, above, because it is assumed that half the annual feed requirement is satisifed by pasture grass and half by locally grown stored feed. This reflects the following assumptions made for this analysis: the length of the grazing season is 6 months per year during which time the feed will consist of 100 percent pasture grass; and, during the remainder of the year when pasture grass is unavailable, feed will consist of 100 percent locally grown vegetation. These assumptions are also reflected in the following equation for milk concentrations

$$C_{mi} = Q\ F_{mi}\ (0.5\ C_{pgi} + 0.5\ C_{hi}) \qquad (10)$$

where C_{mi} is the average concentration of isotope i in milk, pCi/ℓ; and

F_{mi} is the feed to milk activity transfer factor for isotope i, pCi/ℓ per pCi/day ingested (see Table G-3.2).

6. CONCENTRATIONS AT DIFFERENT TIMES

The above equations for calculating environmental media concentrations have been used to estimate concentrations resulting at different times of the model mill's life-cycle and from varying sources. The following sub-sections address the specific methodologies employed to satisfy these varying purposes.

6.1 Concentrations During the Final Year of Actual Milling

The operational lifetime of the model mill is assumed to be 15 years in duration. Average concentrations in environmental media during the 15th year of mill operation have been estimated by assuming no initial concentrations (at t = 0) and by employing a value of 14.5 years for the parameter t appearing in Equations 2, 3, 4, and 6. The resulting environmental media concentrations are those that would exist midway through the final year of actual milling and they are assumed to represent the average concentrations existing during that year.

In the case of multiple operating mills, a value of 14.5 years was again set for the parameter t in Equations 2, 3, 4, and 6. However, the direct air concentrations entering into Equations 1, 4, and 6 were those resulting from all operating mills combined.

6.2 Concentrations After the End of Actual Milling

For the model mill only, average concentrations in environmental media for the 5th year following the end of actual milling were calculated. These concentrations were calculated as the sum of those existing due to releases during the 15-year operational lifetime and due to post-milling tailings pile effluents. The average concentrations during the 5th post-milling year were estimated by calculating concentrations existing 4.5 years after the end of milling.

In order to obtain concentrations 4.5 years after the end of actual milling, due to releases during the operational lifetime, a value of 15.0 years was used for the parameter t appearing in Equations 2, 3, 4, and 6. Since direct air concentrations due to releases during operation vanish, the resulting environmental media concentrations due to those releases, 4.5 years after the end of milling, arise only from residual ground and resuspended air concentrations. Residual ground concentrations were calculated by multiplying the end-of-milling values by the factor

$$\exp\ [(-0.693/50\ \text{years}) \times 4.5\ \text{years}]$$

which represents the fraction remaining after 4.5 years based on an assumed environmental half-life of 50 years. Residual resuspended air concentrations were determined by

$$C_{arip}\ (T_d - 0.5) = 0.01\ C_{adip}\ 10^{-9} \left\{ \exp\ [-\lambda g_i^*\ (T_d - 0.5)] \ldots \right.$$

$$\left. \ldots + \left[\frac{1 - \exp\ (-\lambda_i^* T_o)}{\lambda_i^*} \right] \right\} (3.156 \times 10^7) \qquad (12)$$

where C_{adip} is the direct air concentration of isotope i, in particle size p, resulting from (and during) operational releases, pCi/m³;

$C_{arip}(T_d - 0.5)$ is the residual resuspended air concentration of isotope i, in particle size p, resulting from operational releases, 0.5 years prior to the end of the drying period (T_d years), pCi/m³;

T_d	is the length of the drying period, 5 yrs;
T_o	is the operational lifetime, 15 yrs;
λ_i^*	is the effective decay constant for isotope i on ground, yr^{-1};
0.01	is the deposition velocity of the particle size for which the terminal value of the resuspension factor is 10^{-9} m^{-1}, m/sec;
10^{-9}	is the terminal value of the resuspension factor, m^{-1}; and
3.156×10^7	is sec/yr.

The residual ground and resuspended air concentrations were then added to those calculated on the basis of post-milling release rates, using $t = 4.5$ years in Equations 2, 3, 4, and 6, to obtain total ground and resuspended air concentrations existing 4.5 years after the end of milling. Total air concentrations, total deposition rates, etc., were then calculated in the normal fashion.

6.3 Concentrations for Environmental Dose Commitment Calculations

In this analysis, annual population doses have been calculated based on summations of individual dose commitments due to a one-year exposure period where the one-year exposure period is taken to be either the 15th year of actual milling or the 5th year after milling ends. These calculations yield maximum annual population dose commitments but are not useful for estimating the total radiological impacts of the model mill over the combined 20-year release period.

In order to estimate total annual impacts (from which total impacts over an extended release period can be estimated) the concept of environmental dose commitment is employed with a 100-year integrating period. In this approach the impacts of releases over a one-year period are estimated by summing all resulting population dose commitments over an exposure period of 100 years following release. These environmental dose commitments have been calculated under the assumption that: population doses resulting from a one-year exposure period, to environmental media concentrations resulting from constant releases over 100 years, are equivalent to population doses resulting from a 100-year exposure period, to environmental media concentrations resulting from constant releases over one year.* On this basis the required environmental media concentrations are those average values over the period $t = 100$ years to $t = 101$ years. These are calculated by setting t to a value of 100.5 years in Equations 2, 3, 4, and 6.

References

1. D. C. Kocher, "Nuclear Decay Data for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities", U.S. NRC Report ORNL/NUREG/TM-102, August 1977.

2. Environmental Statement, "Liquid Metal Fast Breeder Reactor Program," Vol. II, WASH-1535, p.4, G-30, 1974.

3. J. F. Fletcher and W. L. Dotson (compilers), "HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry", Hanford Engineering Development Laboratory, HEDL-TME-71-168, December 1971.

4. Y. C. Ng et al., "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere," USAEC Report UCRL-50163, Part IV, 1968.

5. R. S. Booth et al., "A Systems Analysis Methodology for Predicting Dose to Man from a Radioactivity Contaminated Terrestrial Environment," Proceedings of the Third National Symposium on Radioecology, USAEC Report CONF-710501, Oak Ridge, Tenn., pp. 877-893, 1971.

6. R. J. Garner, "Transfer of Radioactive Materials from the Terrestrial Environment to Animals and Man," CRC Press, Cleveland, Ohio, 1972.

7. L. M. McDowell-Boyer et al., "Review and Recommendations of Dose Conversion Factors and Environmental Transport Parameters for Pb-210 and Ra-226," Oak Ridge National Laboratory, NUREG/CR-0574, March 1979.

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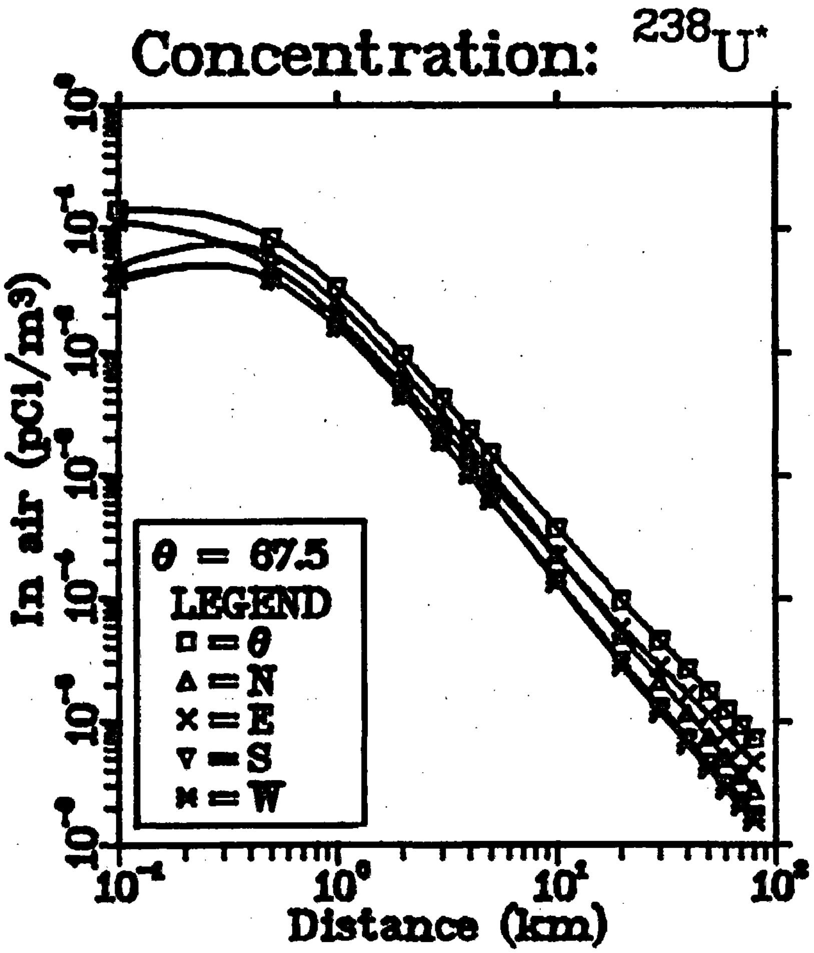
*The validity of this assumption, and the rationale for use of a 100-year integrating period, are addressed in Appendix G-6.

APPENDIX G-4. CONCENTRATIONS OF RADIONUCLIDES IN THE AIR AND ON THE GROUND OF THE MODEL REGION FROM OPERATION OF THE MODEL MILL

This appendix contains graphs and isopleths of the concentrations of various radionuclides in the vicinity of the model mill. Figures G-4.1 through G-4.12 are graphs of air and ground concentrations as a function of distance from the mill. The angle $\theta = 67.5°$ is the ENE direction and represents the angle at which the maximum concentration of radon at a distance of 80 km from the mill was found to occur. Figures G-4.1 through G-4.6 represent concentrations in the air, and Figures G-4.7 through G-4.11 represent ground concentrations. Figure G-4.12 shows radon daughter concentrations in air expressed in working levels (WL). Figures G-4.13 through G-4.18 depict isopleths of concentrations of various radionuclides in the air at distances out to 8 and 80 km. All of the figures in this appendix present concentrations occurring during the 15th year of mill operation.



* *Curve for U-234 is identical.*

Fig. G-4.1. Computed Concentration of U-238 in the Air.

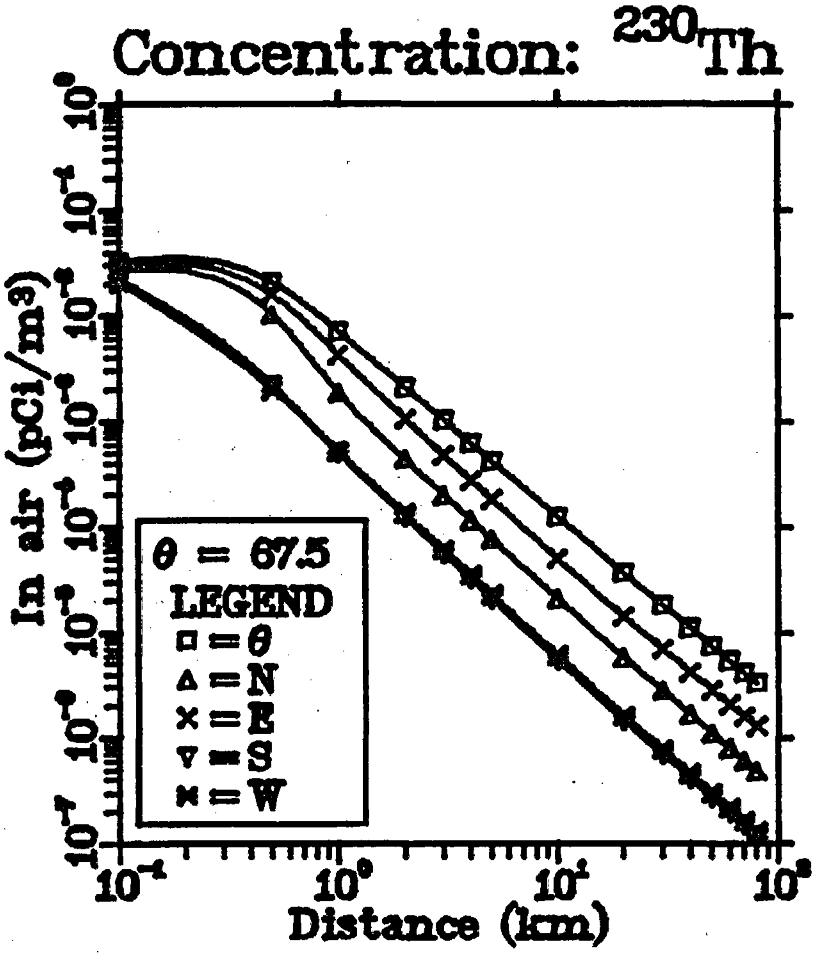


Fig. G-4.2. Computed Concentration of Th-230 in the Air.

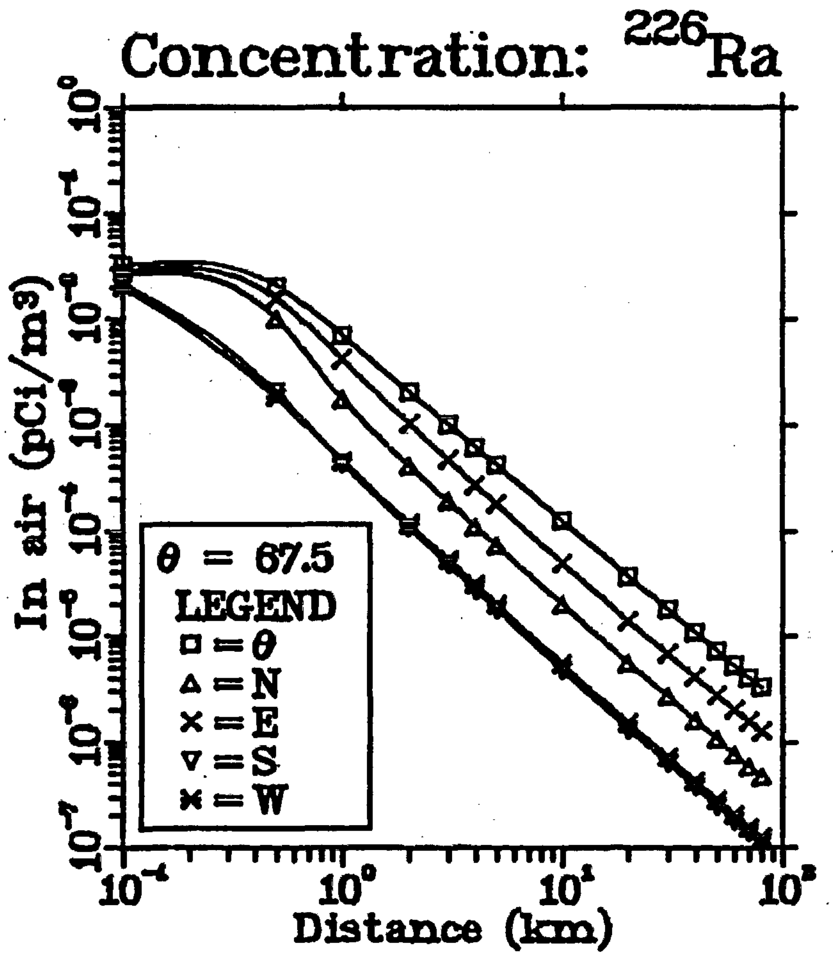


Fig. G-4.3. Computed Concentration of Ra-226 in the Air.

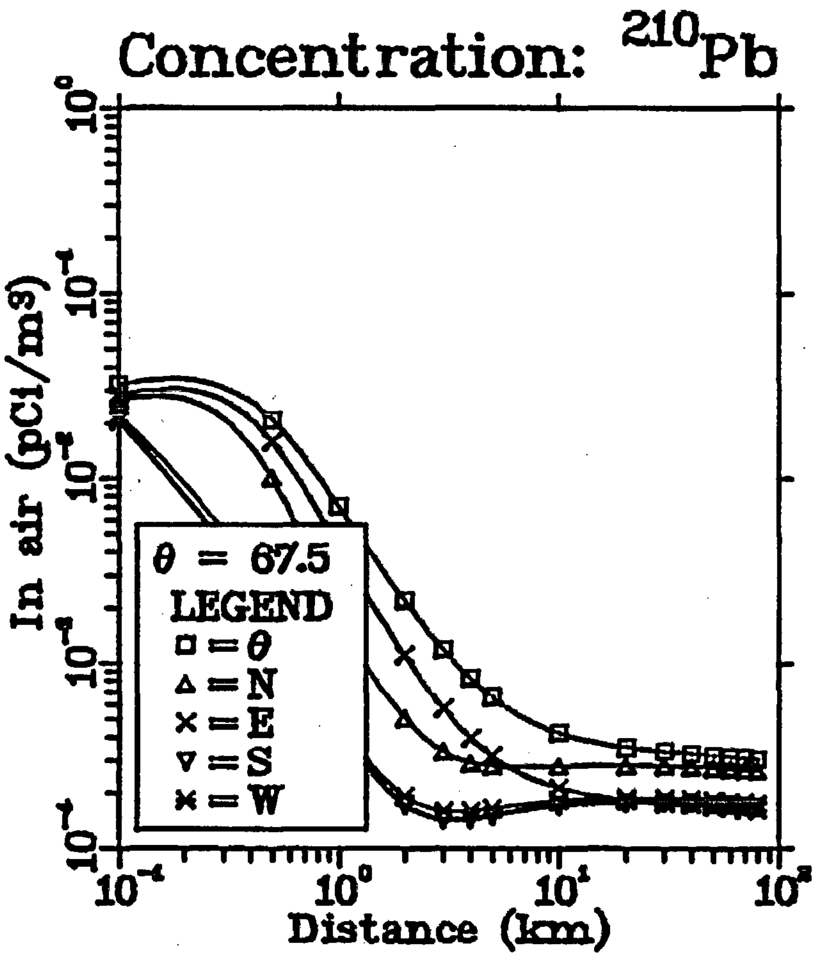


Fig. G-4.4. Computed Concentration of Pb-210 in the Air.

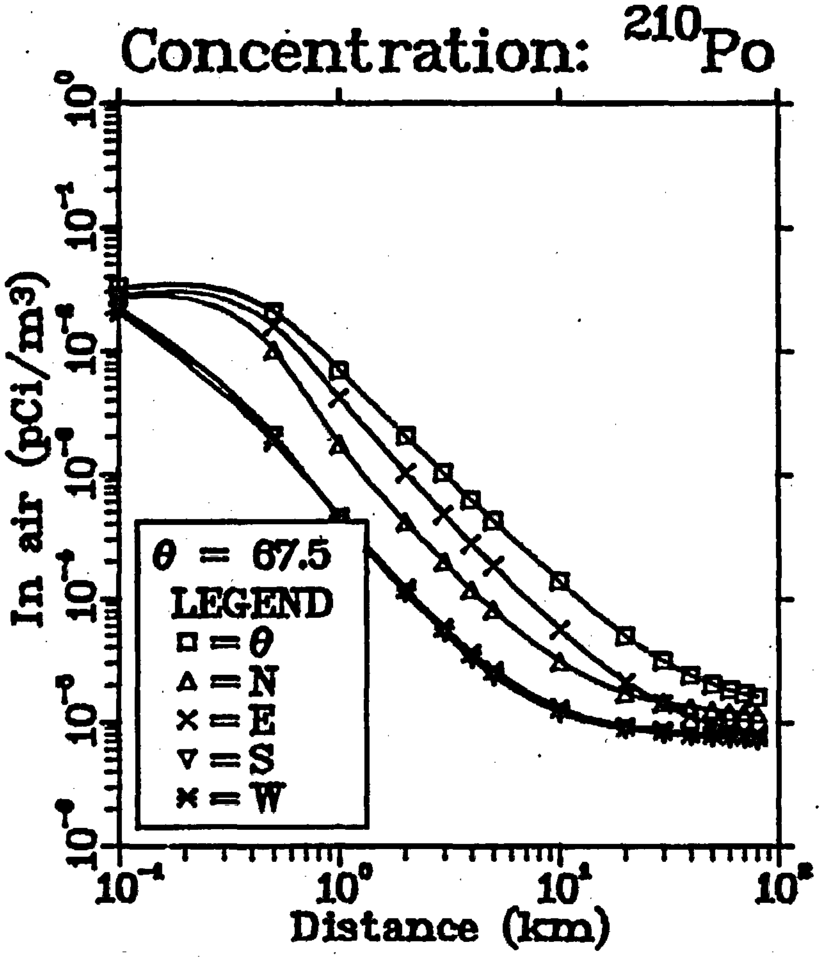


Fig. G-4.5. Computed Concentration of Po-210 in the Air.

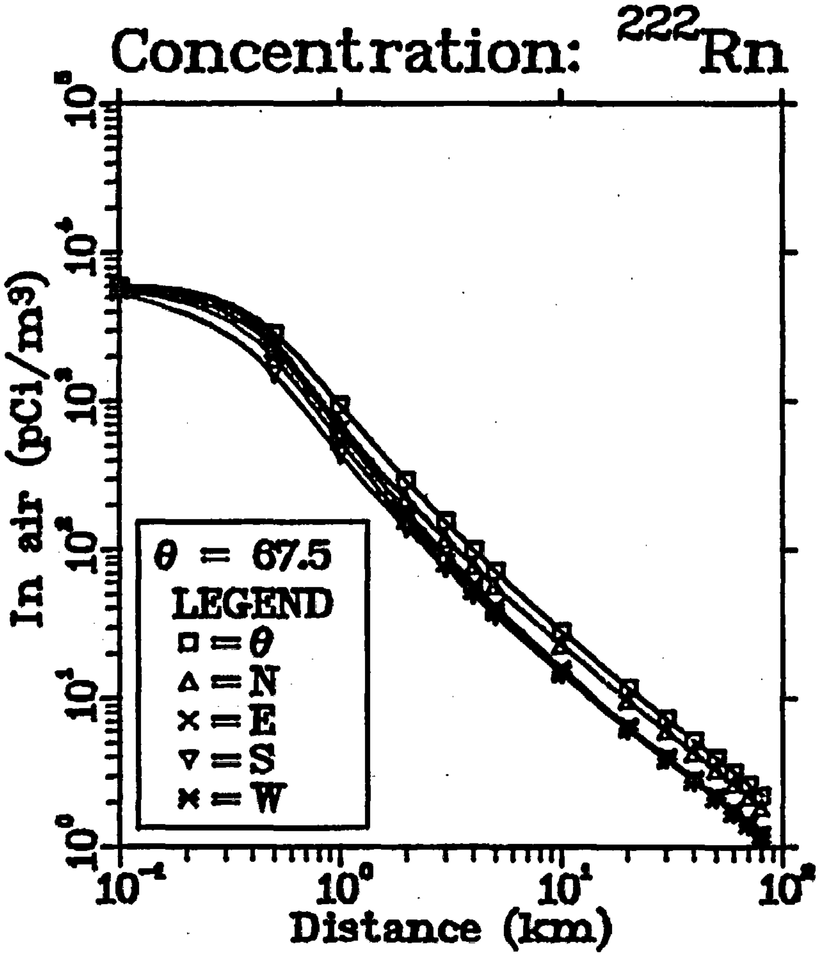
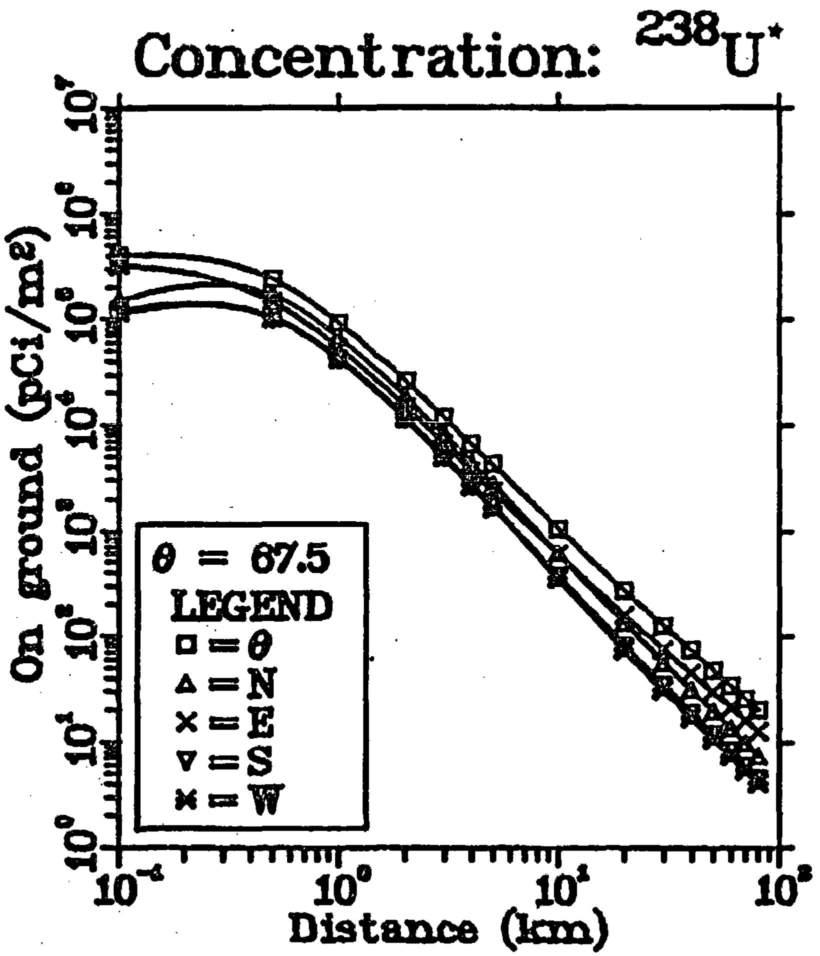


Fig G-4.6. Computed Concentration of Rn-222 in the Air.



** Curve for U-234 is identical.*

Fig. G-4.7. Computed Concentration of U-238 Deposited on the Ground.

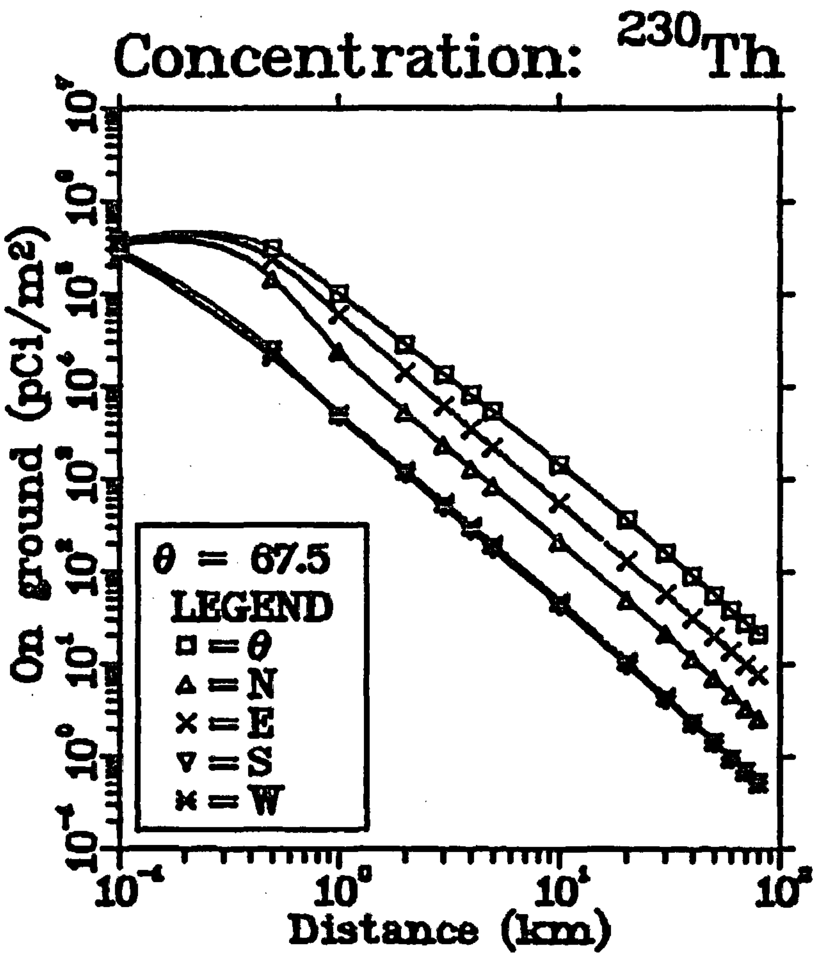


Fig. G-4.8. Computed Concentration of Th-230 Deposited on the Ground.

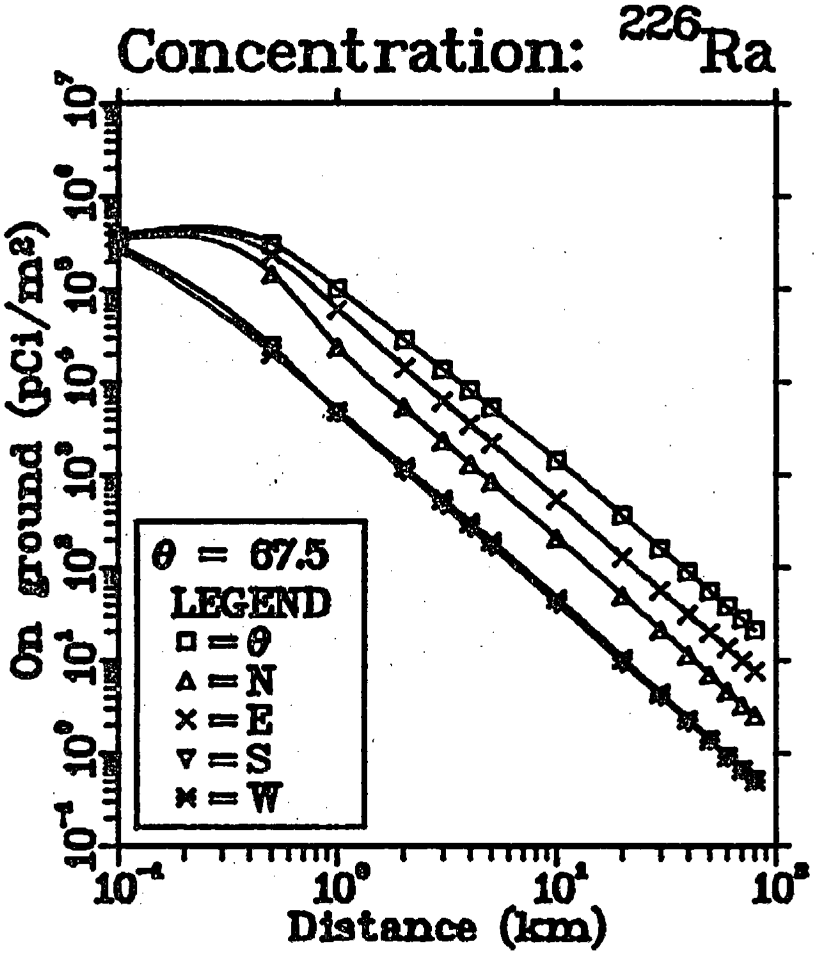


Fig. G-4.9. Computed Concentration of Ra-226 Deposited on the Ground.

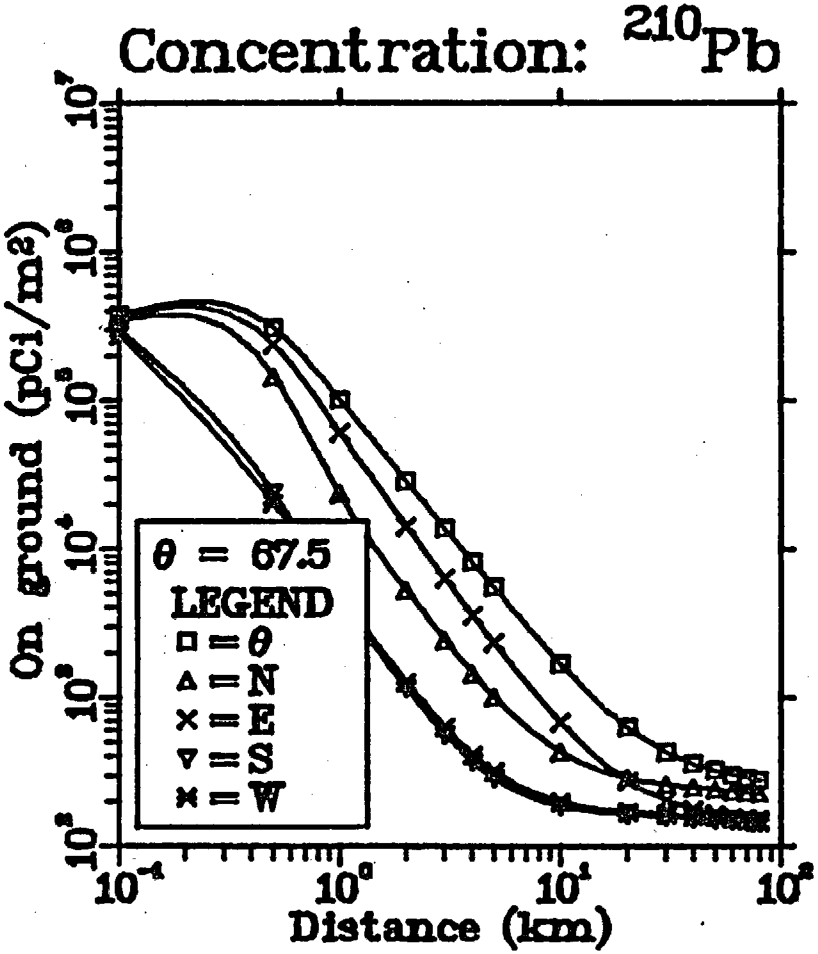


Fig. G-4.10. Computed Concentration of Pb-210 Deposited on the Ground.

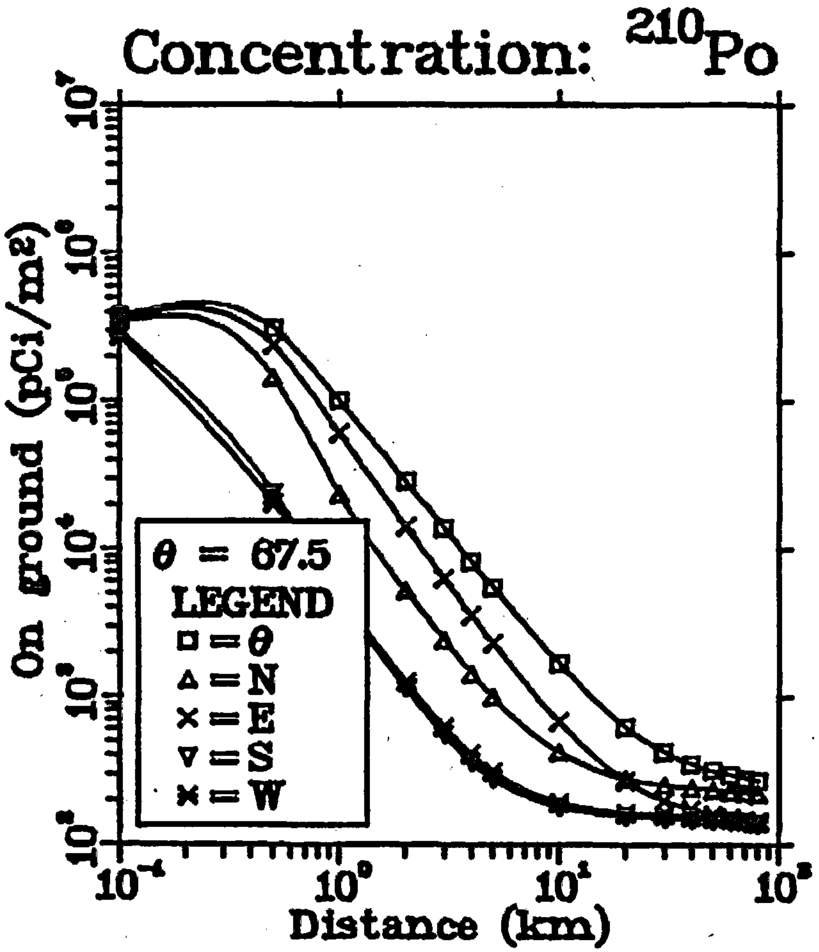


Fig. G-4.11. Computed Concentration of Po-210 Deposited on the Ground.

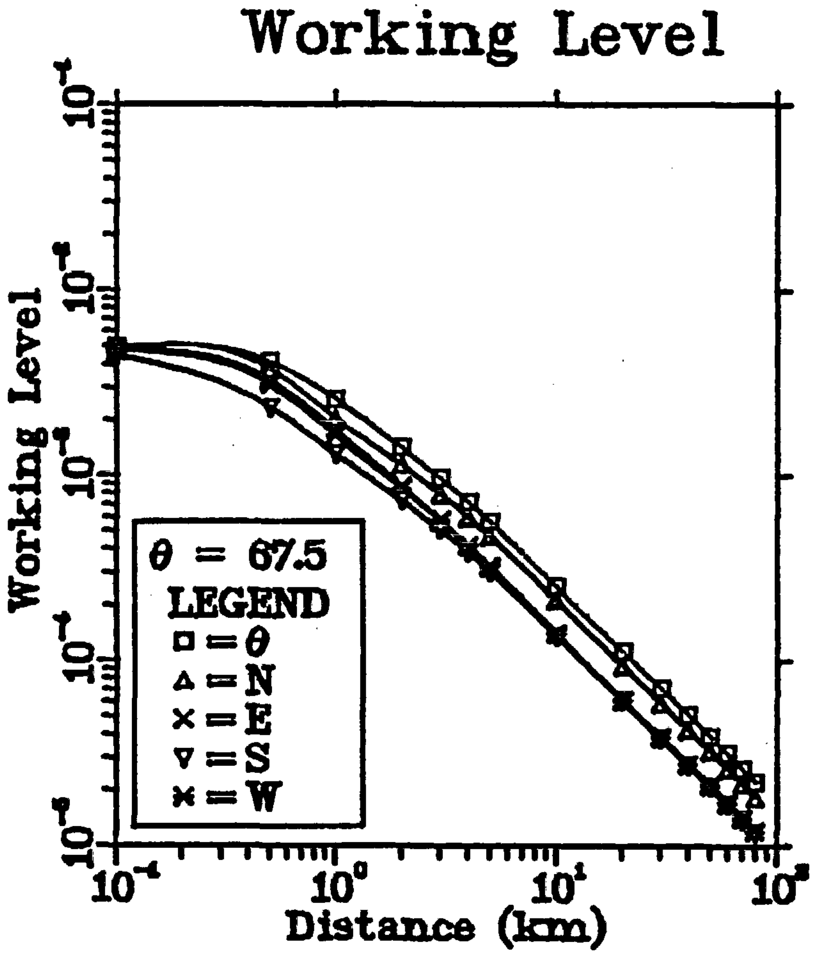


Fig. G-4.12. Working Level for Rn-222 Daughters.

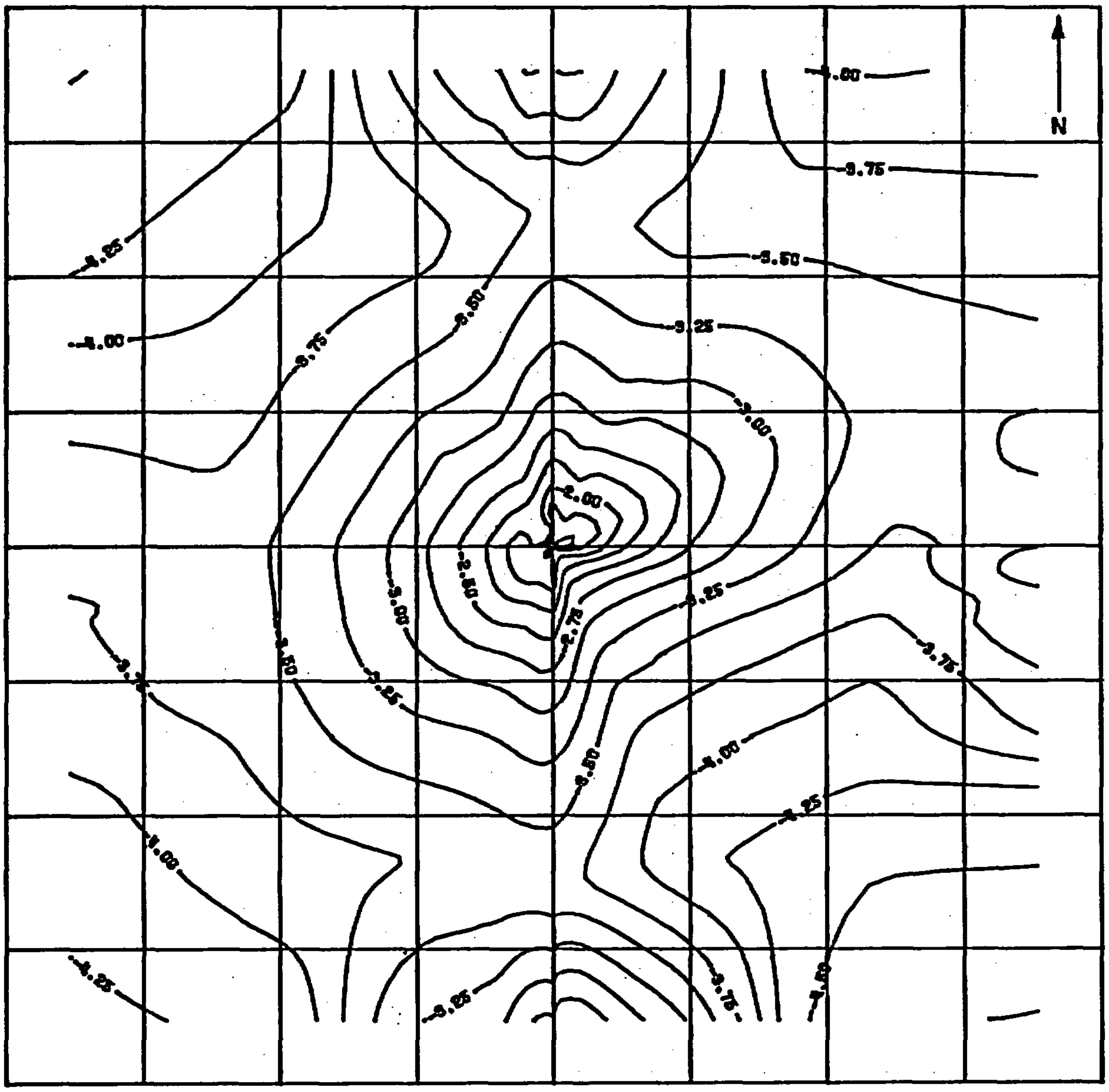


Fig. G-4.13. Predicted U-238 Air Concentration Isopleths within 8 km of the Model Mill. [Grid spacing is 2 km. Numbers are negative and equal log (pCi per cubic meter of air/3 pCi/m^3).]

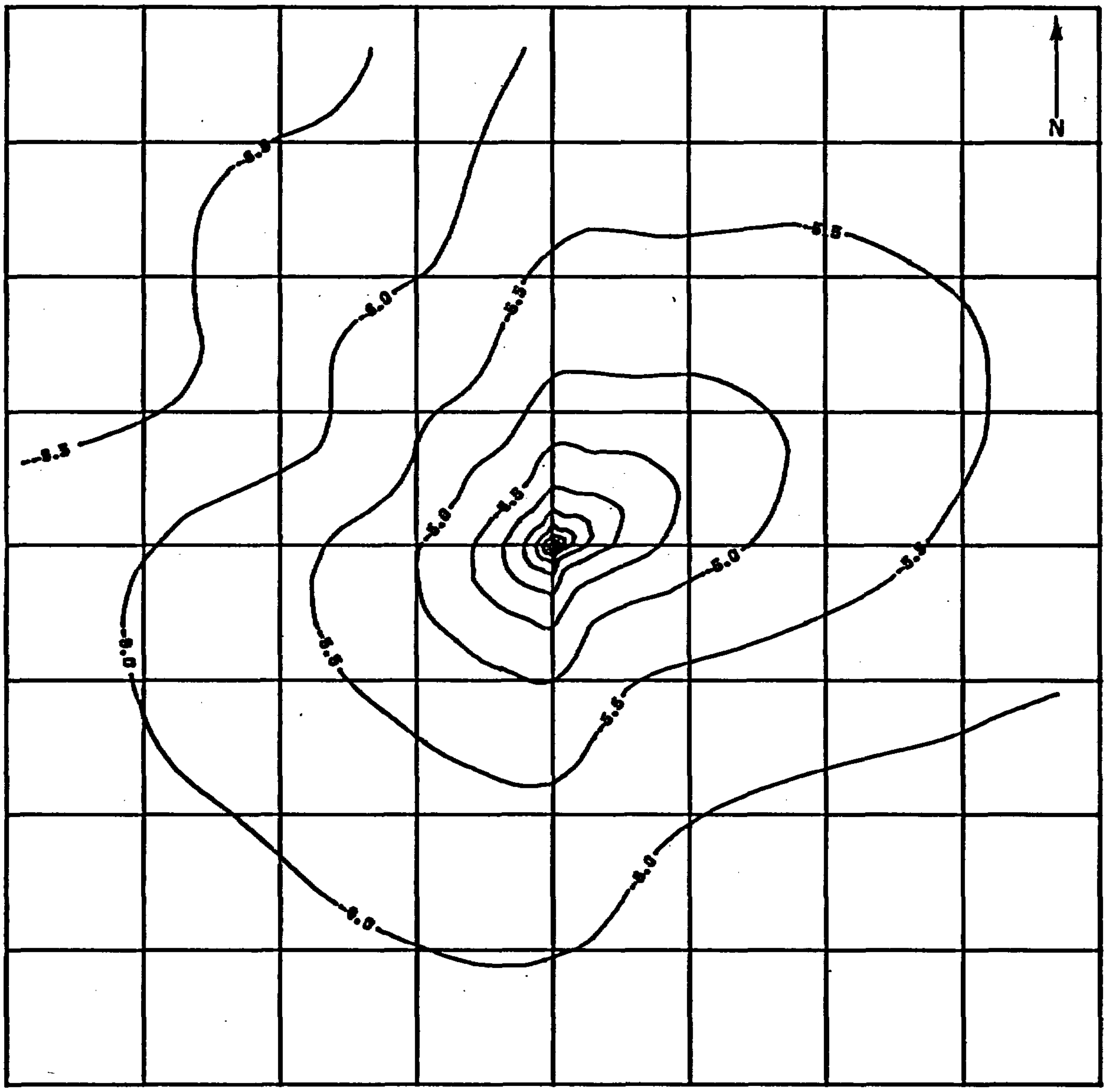


Fig. G-4.14. Predicted U-238 Air Concentration Isopleths within 80 km of the Model Mill. [Grid spacing is 20 km. Numbers are negative and equal log (pCi per cubic meter of air/3 pCi/m^3).]

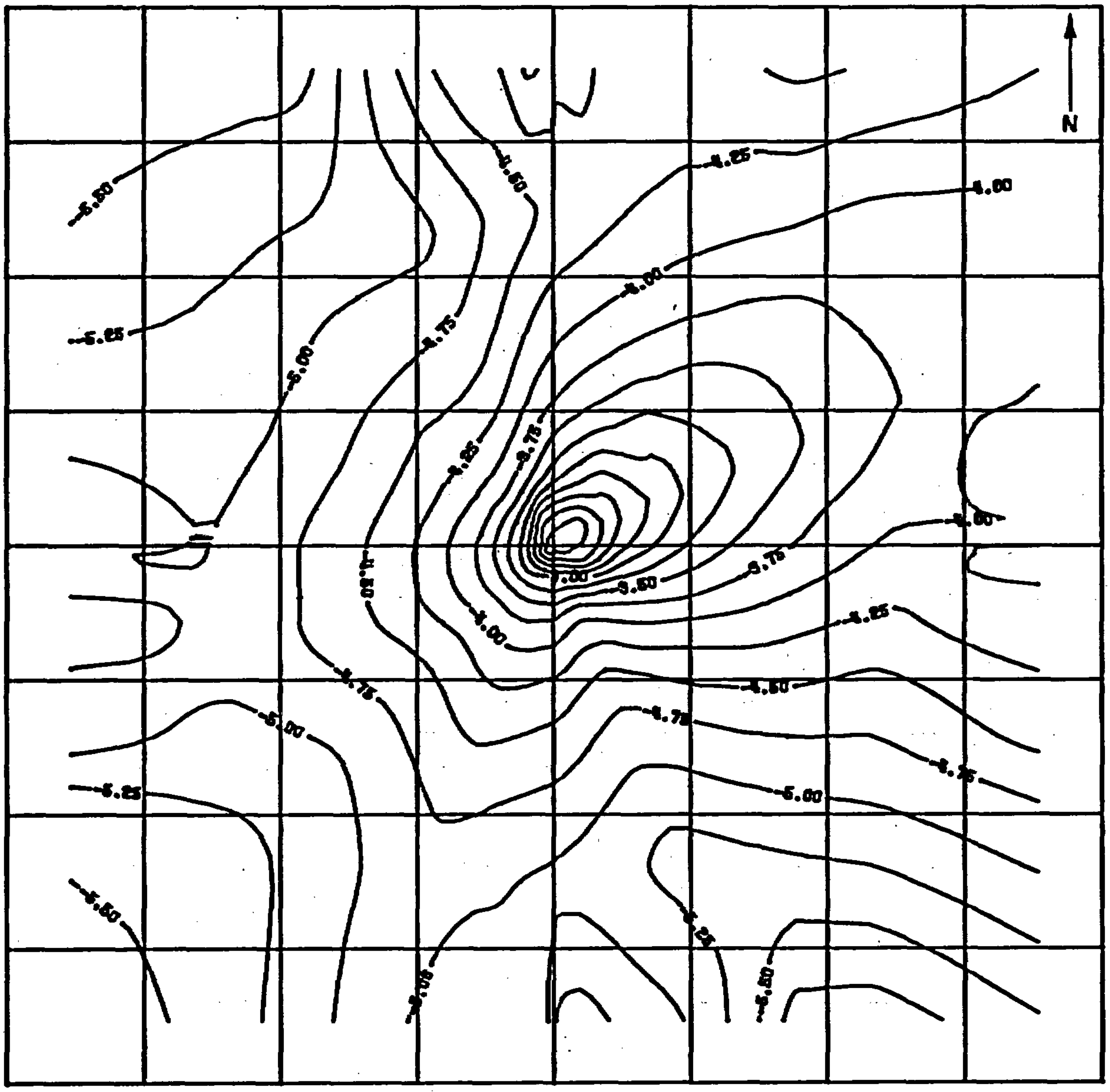


Fig. G-4.15. Predicted Ra-226 Air Concentration Isopleths within 8 km of the Model Mill. [Grid spacing is 2 km. Numbers are negative and equal log (pCi per cubic meter of air/2 pCi/m^3).]

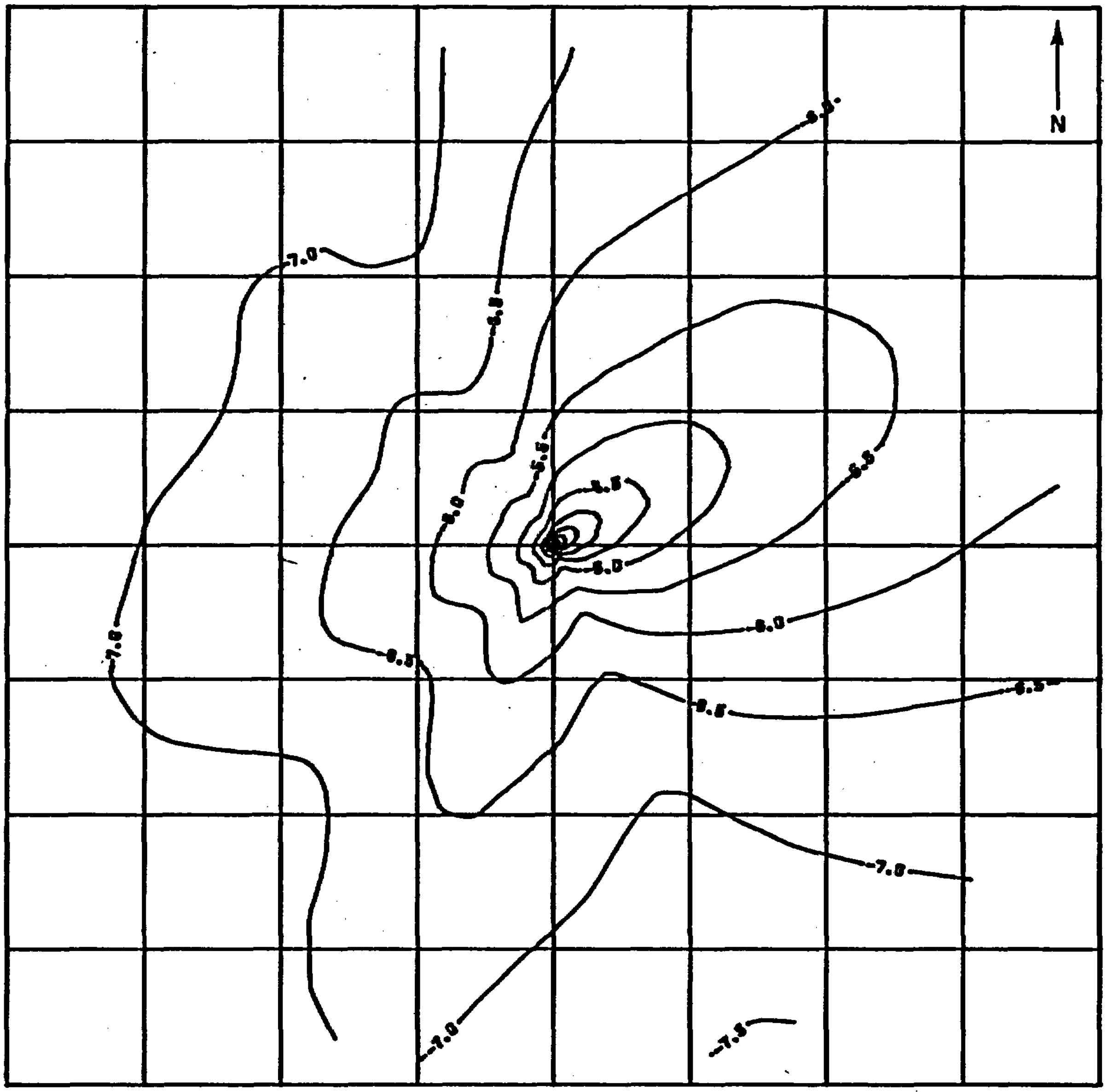


Fig. G-4.16. Predicted Ra-226 Air Concentration Isopleths within 80 km of the Model Mill. [Grid spacing is 20 km. Numbers are negative and equal log (pCi per cubic meter of air/2 pCi/m^3).]

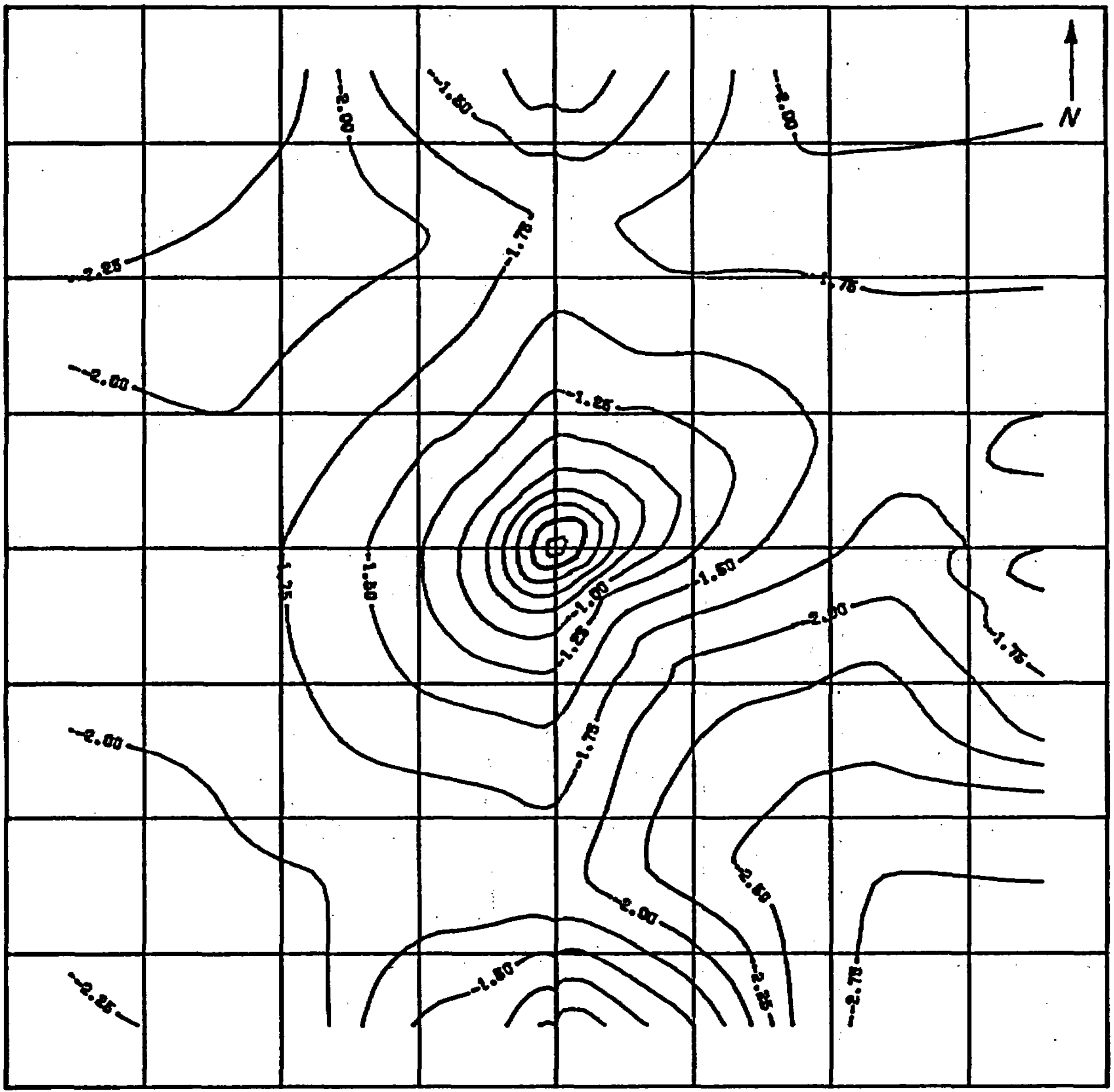


Fig. G-4.17. Predicted Rn-222 Air Concentration Isopleths within 8 km of the Model Mill. [Grid spacing is 2 km. Numbers are negative and equal log (pCi per cubic meter of air/3000 pCi/m^3).]

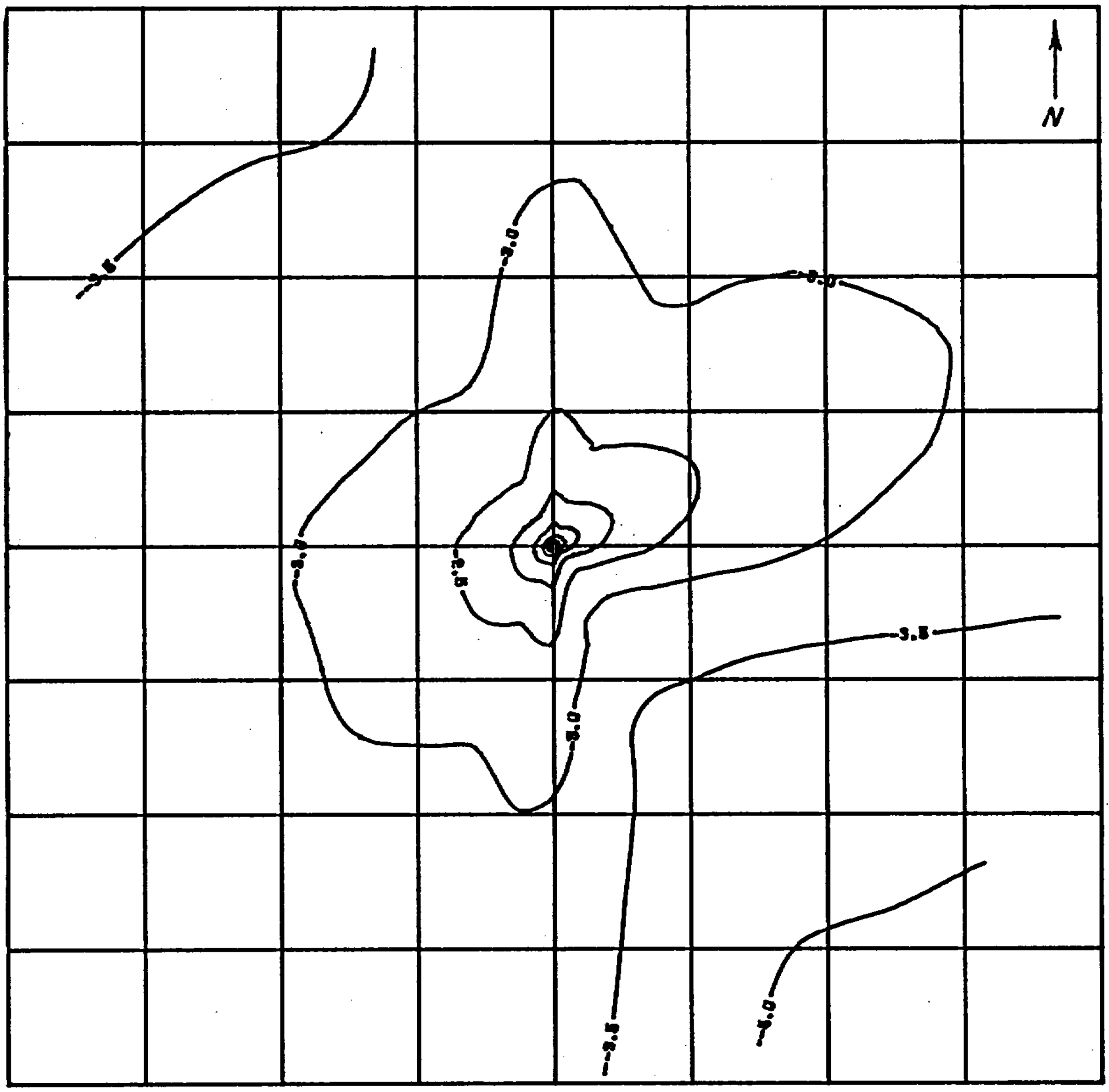


Fig. G-4.18. Predicted Rn-222 Air Concentration Isopleths within 80 km of the Model Mill. [Grid spacing is 20 km. Numbers are negative and equal log (pCi per cubic meter of air/3000 pCi/m^3).]

APPENDIX G-5. DOSE CALCULATIONS FOR INDIVIDUALS

Doses to individuals have been calculated for all significant exposure pathways routinely present in the immediate environs of uranium milling facilities. These exposure pathways include inhalation, external exposure to air and ground concentrations, and ingestion of vegetables and meat. Milk ingestion doses to individuals have also been included although that pathway has not been routinely present as indicated by staff analyses of radiological impacts for actual uranium milling sites.

Internal doses (from inhalation or ingestion pathways) have been calculated using dose conversion factors which yield the 50-year internal dose commitment, i.e., the entire dose insult received over a period of 50 years following intake into the body. Annual doses given for individuals are the 50-year dose commitments resulting from a one-year exposure period. The one-year exposure period is taken to be the final year of actual milling or the fifth year following the end of the operational mill lifetime.

1. INHALATION DOSES

Inhalation doses to individuals are calculated using total air concentrations, which are determined using the methodology described in Appendices G-2 and G-3, and the inhalation dose conversion factors described below.

1.1 Inhalation Dose Conversion Factors for Particulates

The inhalation dose conversion factors for radioactive particulate materials used in this analysis are presented in Tables G-5.1 and G-5.2. With the exception of the dose conversion factors presented for "mass average lung," these dose conversion factors have been computed by Argonne National Laboratory's UDAD computer code (Ref. 1) in accordance with the Task Group Lung Model (TGLM) of the International Commission on Radiological Protection (Ref. 2). Dose conversion factors for the mass average lung have been computed by mass-averaging the UDAD-calculated dose conversion factors for the four regions of the TGLM: nasopharyngeal, tracheobronchial, pulmonary, and lymph. Ordinarily, the dose computed specifically for the pulmonary region is reported or presented as the "lung" dose. For the principal lung dose contributors (uranium and thorium), doses computed for the mass average lung are slightly higher than those calculated for the pulmonary region. The net overall effect, considering all isotopes, is thus a slight increase in the reported lung dose.

In addition to the physical characteristics of the particulate matter involved, use of the TGLM demands the assignment of a solubility class, denoted by Y (years; for slowly soluble or insoluble compounds), W (weeks; for moderately soluble compounds), or D (days; quite soluble). Solubility classifications have been assigned on the basis of experimental data reported and summarized by Kalkwarf in NUREG/CR-0530.[3] These data indicate that thorium, lead, and polonium are 100% class Y in ore, yellowcake, or tailings dusts. Radium was determined to be best characterized by the split-solubility classification 10% class D, 90% class Y. Uranium in ore dust was determined to be 100% class W; uranium solubility for tailings dusts was not analyzed and is assumed to be class Y. Data for uranium in yellowcake were mixed and showed a pronounced dependence on the specific source of the yellowcake sample. Results reported by Kalkwarf indicate a split-solubility classification is appropriate, and on review of those results (particularly those given on page 55 of NUREG/CR-0530) the staff has assumed uranium in yellowake to be 50% class D and 50% class Y. The computed inhalation dose conversion factors are given in Tables G-5.1 and G-5.2 for nonoccupational and occupational exposure, respectively.

Based on the present dose conversion factors, particulate inhalation doses to individuals are calculated using the following equation:

$$d_j(\text{inh}) = \sum_{ip} C_{aip} \, DCF_{ijp}(\text{inh}) \qquad (1)$$

Table G-5.1 Inhalation Dose Conversion Factors For Non-Occupational Exposure

	mrem/yr per pCi/m^3					
Particle Size = 0.3 Microns	PB210	P0210				
Whole Body	7.46E+00	1.29E+00				
Bone	2.32E+02	5.24E+00				
Kidney	1.93E+02	3.87E+01				
Liver	5.91E+01	1.15E+01				
Mass Average Lung	6.27E+01	2.66E+02				
Particle Size = 1.0 Microns Density = 8.9 g/cm^3	U238	U234	TH230	RA226	PB210	P0210
Whole Body	9.82E+00	1.12E+01	1.37E+02	3.58E+01	4.66E+00	5.95E-01
Bone	1.66E+02	1.81E+02	4.90E+03	3.58E+02	1.45E+02	2.43E+00
Kidney	3.78E+01	4.30E+01	1.37E+03	1.26E+00	1.21E+02	1.79E+01
Liver	0.0	0.0	2.82E+02	4.47E-02	3.69E+01	5.34E+00
Mass Average Lung	1.07E+3	1.21E+3	2.37E+03	4.88E+03	5.69E+02	3.13E+02
Particle Size = 1.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	P0210
Whole Body	4.32E+00	4.92E+00	1.66E+02	3.09E+01	4.36E+00	4.71E-01
Bone	7.92E+01	7.95E+01	5.95E+03	3.09E+02	1.35E+02	1.92E+00
Kidney	1.66E+01	1.89E+01	1.67E+03	1.09E+00	1.13E+02	1.42E+01
Liver	0.0	0.0	3.43E+02	3.87E-02	3.45E+01	4.22E+00
Mass Average Lung	1.58E+02	1.80E+02	3.22E+03	6.61E+03	7.72E+02	4.20E+02
Particle Size = 5.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	P0210
Whole Body	1.16E+00	1.32E+00	1.01E+02	4.00E+01	4.84E+00	7.10E-01
Bone	1.96E+01	2.14E+01	3.60E+03	4.00E+02	1.50E+02	2.89E+00
Kidney	4.47E+00	5.10E+00	1.00E+03	1.41E+00	1.25E+02	2.13E+01
Liver	0.0	0.0	2.07E+02	4.97E-02	3.83E+01	6.36E+00
Mass Average Lung	1.24E+03	1.42E+03	1.38E+03	2.84E+03	3.30E+02	1.88E+02
Particle Size = 35.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	P0210
Whole Body	7.92E-01	9.02E-01	5.77E+01	3.90E+01	4.43E+00	7.28E-01
Bone	1.34E+01	1.46E+01	2.07E+03	3.90E+02	1.38E+02	2.96E+00
Kidney	3.05E+00	3.47E+00	5.73E+02	1.38E+00	1.15E+02	2.19E+01
Liver	0.0	0.0	1.19E+02	4.85E-02	3.51E+01	6.52E+00
Mass Average Lung	3.33E+02	3.80E+02	3.71E+02	7.64E+02	8.70E+01	5.75E+01

Table G-5.2 Inhalation Dose Conversion Factors For Occupational Exposure (mrem/yr per pCi/m^3)[a]

Yellowcake Dust (Particle Size = 1.0 Microns, Density = 8.9 g/cm^3)

Organ	U-238	U-234
Average Lung	3.57 E+02	4.03 E+02
Whole Body	3.27	3.73
Bone	5.53 E+01	6.03 E+01

Uranium Ore Dust (Particle size = 5.0 Microns; Density = 2.4 g/cm^3)

Organ	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Average Lung	2.44 E+01	2.77 E+01	4.60 E+02	9.47 E+02	1.10 E+02	6.27 E+01
Whole Body	1.64	1.87	3.37 E+01	1.33 E+01	1.61	2.37 E-01
Bone	2.77 E+01	3.02 E+01	1.20 E+03	1.33 E+02	5.00 E+01	9.63 E-01

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[a] The dose conversion factors given are for an occupational exposure of 40 hrs/week; they can be converted to continuous exposure (168 hrs/week) by multiplying by a factor of 3.

where

C_{aip}	is the total air concentration of isotope i, in particle size p, pCi/m^3;
$d_j(inh)$	is the resulting inhalation dose to organ j, mrem/yr; and
$DCF_{ijp}(inh)$	is the inhalation dose conversion factor for isotope i, particle size p, and organ j, mrem/yr per pCi/m^3.

1.2 Inhalation Dose Conversion Factor for Radon Daughters

The only pathway of radon gas into the body is by inhalation, but it is not readily absorbed or deposited in the lung; thus, the dose from radon to the lung or other body tissue is not of great significance. However, radon decays with a 3.82-day half-life through a series of short-lived daughter products (longest half-life in this chain is 27 minutes) to lead-210 with a 22-year half-life. The short-lived daughters, rather than radon itself, are of primary concern relative to the inhalation pathway.

Even though the dose rate from radon in the atmosphere is small, the dose rate from radon daughters may provide significant exposure (Refs. 4-6). Radon daughters formed in air are rapidly attached to aerosol particles as a result of their rapid diffusion. Rates of attachment are dependent on the concentration of particles in the atmosphere, the ambient humidity (Ref. 2 and 7), and the surface-to-volume ratio of the particles. The observed mean half-life before attachment of a positive ion to atmospheric particles is less than 20 minutes. Since the first daughter product, Po-218, has a radioactive half-life of about three minutes, it is likely to decay to Pb-214 before becoming attached to an aerosol particle. Because of their longer radioactive half-lives, the other radon daughters are more likely to attach to atmospheric aerosols than is Po-218.

Unattached radon daughters are very readily deposited and retained on respiratory surfaces. The dose rate from radon daughters associated with aerosols, as for other particulates, is dependent on the particle's physical characteristics, such as diameter, shape, and density. Also, the ratio of concentrations of radon daughters in the atmosphere to the concentration of radon is related to the mixing and dilution volume. Under equilibrium conditions, the activity of each daughter is equal to the activity of radon. A condition of equilibrium can be approached in a tightly enclosed volume, such as a poorly ventilated room.

In this analysis doses to the critical lung tissue, the bronchial epithelium, from inhalation of short-lived radon daughters are computed on the basis of 100 percent indoor exposure in an adequately ventilated room using a dose conversion factor of 0.625 mrem/yr indoors per pCi/m^3 of Rn-222 in outdoor air. The basis upon which the staff has relied for this dose conversion factor consists of three major component parts as follow:

(1) the average indoor working level (WL*) concentration resulting from an outdoor Rn-222 concentration of 1 pCi/m³ is approximately 5.0×10^{-6} WL;

(2) the number of cumulative working-level-months (WLM) of radon daughter exposure for an average individual surrounded by air at a constant concentration of one WL is about 25 WLM/yr; and

(3) the committed dose equivalent to the bronchial epithelium (basal cell nuclei of segmented bronchi) per unit WLM exposure is about 5 rem (5000 mrem).

These factors have all entered into the equation below which yields the Rn-222 short-lived daughter inhalation dose conversion factor used by the staff

$$\frac{0.625 \text{ mrem}}{\text{pCi/m}^3} = \left(\frac{5.0 \times 10^{-6} \text{ WL}}{\text{pCi/m}^3}\right) \left(\frac{25 \text{ WLM/yr}}{\text{WL}}\right) \left(\frac{5 \times 10^3 \text{ mrem}}{\text{WLM}}\right) \qquad (2)$$

where the basis for each of the three component factors entering into the above equation is as detailed in the following paragraphs.

In a normally ventilated dwelling or other structure the indoor Rn-222 concentration will be approximately the same as that in the air immediately outside. However, the concentrations of the short-lived daughters (Po-218, Pb-214, and Bi-214) may be higher than they are outdoors due to equilibration. Under adequate ventilation conditions the concentration ratios of the short-lived daughters to that of the parent Rn-222 may be expressed as 1.0/0.9/0.51/0.35 (Ref. 8). Based on these concentration ratios, and an outdoor Rn-222 concentration of 1 pCi/m³, the indoor air will be at a concentration of approximately 5×10^{-6} WL (Ref. 9).

The working-level-month (WLM) is a unit used to express occupational exposure of working miners to short-lived radon daughter air concentrations. One WLM is defined as exposure for the number of WLM per year of constant exposure to a one-WL concentration, for an average individual, is given by

$$\frac{25 \text{ WLM/yr}}{\text{WL}} = 0.5 \left(\frac{12 \text{ WLM/WL-yr}}{40 \text{ hrs/wk} \times 52 \text{ wks/yr}}\right) (8760 \text{ hrs/yr}) \qquad (3)$$

The BEIR Report (Ref. 10) presents a detailed discussion of radon daughter dosimetry and states that "1 rad/WLM is probably close to the upper limit for a reasonably uniform dose to the basal cell layer of the epithelium of the larger bronchi on a probabilities basis." Based on the figure of 0.5 rad/WLM adopted for use in the BEIR Report, and a quality factor of 10 for alpha radiation (Refs. 9 and 10), a figure of 5 rem/WLM is derived.

2. EXTERNAL DOSES

External doses resulting from exposure to air and ground activity concentrations are computed by using the dose conversion factors presented in Table G-5.3 (Ref. 1) and assuming 100 percent occupancy at a given location. Indoor exposure is assumed to occur 14 hours per day at a dose rate of 70 percent of the outdoor dose rate. This provides an effective dose reduction factor of 0.825. The following equation is used to calculate external doses:

$$d_j(\text{ext}) = 0.025 \sum_i C_{ai} \, DCF_{ij}(\text{cld}) + C_{gi} \, DCF_{ij}(\text{gnd}) \qquad (4)$$

where	C_{ai}	is the total air concentration of isotope i, pCi/m³;
	C_{gi}	is the total ground concentration of isotope i, pCi/m²;
	$DCF_{ij}(\text{cld})$	is the dose factor for cloud exposure, for isotope i, organ j, mrem/yr per pCi/m³;
	$DCF_{ij}(\text{gnd})$	is the dose factor for ground exposure, for isotope i, organ j, mrem/yr per pCi/m²; and
	0.825	is the effective reduction factor due to structural shielding provided during part-time indoor exposure.

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*Short-lived radon daughter concentrations are expressed in units called working levels (WL). One WL is defined as any combination of short-lived radon daughter concentrations in one liter of air that will produce 1.3×10^5 MeV of alpha energy in their complete decay to Pb-210. A working-level-month (WLM) is defined in terms of working miners and represents occupational exposure to a one-WL concentration for one working month (about 170 hours).

Table G-5.3 Dose Conversion Factors for External Exposure

Dose Factors for External Doses from Air Concentrations, mrem/yr per pCi/m^3

ISOTOPE	SKIN	WHOLE BODY*
U238	1.05E-05	1.57E-06
TH234	6.63E-05	5.24E-05
PAM234	8.57E-05	6.64E-05
U234	1.36E-05	2.49E-06
TH230	1.29E-09	3.59E-06
RA226	6.00E-05	4.90E-05
RN222	3.46E-10	2.83E-06
PO218	8.18E-07	6.34E-07
PB214	2.06E-03	1.67E-03
BI214	1.36E-02	1.16E-02
PO214	9.89E-07	7.66E-07
PB210	4.17E-05	1.43E-05

Dose Factors for External Doses from Ground Concentrations, mrem/yr per pCi/m^2

ISOTOPE	SKIN	WHOLE BODY*
U238	2.13E-06	3.17E-07
TH234	2.10E-06	1.66E-06
PAM234	1.60E-06	1.24E-06
U234	2.60E-06	4.78E-07
TH230	2.20E-06	6.12E-07
RA226	1.16E-06	9.47E-07
RN222	6.15E-08	5.03E-08
PO218	1.42E-08	1.10E-08
PB214	3.89E-05	3.16E-05
BI214	2.18E-04	1.85E-04
PO214	1.72E-08	1.33E-08
PB210	6.65E-06	2.27E-06

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*Doses to internal body organs are assumed to be the same as computed for the whole body.

3. INGESTION DOSES

Ingestion doses are calculated for ingestion of vegetables, meat (beef, fresh pork, and lamb), and milk. Ingestion doses are based on environmental concentrations established using Equations 8, 9, and 10 of Appendix G-3, ingestion rates presented in Table G-5.4 and dose conversion factors given in Table G-5.5 (Refs. 1 and 11). Vegetable ingestion doses are computed under the assumption that an average of 50 percent of the initial activity will be lost in food preparation (Ref. 12), usually involving washing, peeling, boiling, etc. The following equation is employed to compute vegetable ingestion doses

$$d_{jk}(veg) = 0.5 \sum_{iv} U_{vk} C_{vi} DCF_{ijk}(ing) \qquad (5)$$

where

C_{vi}	is the concentration of isotope i in vegetation v, pCi/kg;
$d_{jk}(veg)$	is the resulting vegetable ingestion dose to organ j of an individual in age group k, mrem/yr;
$DCF_{ijk}(ing)$	is the ingestion dose conversion factor for isotope i, organ j, and age group k, mrem/pCi ingested (see Table G-5.5 for values);
U_{vk}	is the ingestion rate of vegetation type v by an individual in age group k; kg/yr (see Table G-5.4 for values); and
0.5	is the fraction of initial vegetable activity remaining after preparation for the table, dimensionless (Ref. 12).

Table G-5.4 Food Ingestion Rates

	Ingestion Rates by Age Group,* kg/yr			
	Infant	Child	Teen	Adult
I. Vegetables (Total):	-	48	76	105
a) Edible Above Ground:	-	17	29	40
b) Potatoes	-	27	42	60
c) Other Below Ground:	-	3.4	5.0	5.0
II. Meat (beef, fresh pork, and lamb):	-	28	45	78
III. Milk (liters/yr):	208	208	246	130

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*All data taken from Reference 12. Ingestion rates are averages for typical rural farm households. No allowance is credited for portions of the year when locally or home grown food may not be available.

Doses from meat ingestion are calculated by

$$d_{jk}(\text{meat}) = U_{bk} \sum_i C_{bi}\ DCF_{ijk}(\text{ing}) \qquad (6)$$

where C_{bi} is the concentration of isotope i in meat, pCi/kg;

$d_{jk}(\text{meat})$ is the resulting meat ingestion dose to organ j of an individual in age group k, mrem/yr; and

U_{bk} is the meat ingestion rate for age group k, kg/yr (see Table G-5.4 for values).

The dose to an individual from milk ingestion is given by

$$d_{jk}(\text{milk}) = U_{mk} \sum_i C_{mi}\ DCF_{ijk}(\text{ing}) \qquad (7)$$

where C_{mi} is the concentration of isotope i in milk, pCi/l;

$d_{jk}(\text{milk})$ is the resulting milk ingestion dose to organ j of an individual in age group k, mrem/yr; and

U_{mk} is the annual milk ingestion rate for age group k, l/yr.

Total ingestion doses to individuals, for this analysis, are computed as the sum of the vegetable, meat, and milk ingestion doses using the following equation

$$d_{jk}(\text{ing}) = d_{jk}(\text{veg}) + d_{jk}(\text{meat}) + d_{jk}(\text{milk}) \qquad (8)$$

where $d_{jk}(\text{ing})$ is the total ingestion dose to organ j of an individual in age group k, mrem/yr.

4. INDIVIDUAL DOSE TOTALS

Individual dose totals are calculated for dual purposes: evaluating compliance with 10 CFR 20 (ALARA), and evaluating compliance with 40 CFR 190, which applies a limit on total doses excluding contributions from Rn-222 and daughters. Dose totals to individuals are calculated for both purposes using the following equation

$$d_{jk}(\text{tot}) = d_j(\text{inh}) + d_j(\text{ext}) + d_{jk}(\text{ing}) \qquad (9)$$

Table G-5.5. Ingestion Dose Conversion Factors

Internal Dose Conversion Factors by Organ and Age, mrem per pCi ingested

Age Group	Organ	238U	234U	234TH	230TH	226RA*	210PB	210BI	210PO
Infant	Wh. Bod	3.33E-04	3.80E-04	2.00E-08	1.06E-04	1.07E-02	2.38E-03	3.58E-07	7.41E-04
	Bone	4.47E-03	4.88E-03	6.92E-07	3.80E-03	9.44E-02	5.28E-02	4.16E-06	3.10E-03
	Liver	0.	0.	3.77E-08	1.90E-04	4.76E-05	1.42E-02	2.68E-05	5.93E-03
	Kidney	9.28E-04	1.06E-03	1.39E-07	9.12E-04	8.71E-04	4.33E-02	2.08E-04	1.26E-02
Child	Wh. Bod	1.94E-04	2.21E-04	9.88E-09	9.91E-05	9.87E-03	2.09E-03	1.69E-07	3.67E-04
	Bone	3.27E-03	3.57E-03	3.42E-07	3.55E-03	8.76E-02	4.75E-02	1.97E-06	1.52E-03
	Liver	0.	0.	1.51E-08	1.78E-04	1.84E-05	1.22E-02	1.02E-05	2.43E-03
	Kidney	5.24E-04	5.98E-04	8.01E-08	8.67E-04	4.88E-04	3.67E-02	1.15E-04	7.56E-03
Teenager	Wh. Bod	6.49E-05	7.39E-05	3.31E-09	6.00E-05	5.00E-03	7.01E-04	5.66E-08	1.23E-04
	Bone	1.09E-03	1.19E-03	1.14E-07	2.16E-03	4.90E-02	1.81E-02	6.59E-07	5.09E-04
	Liver	0.	0.	6.68E-09	1.23E-04	8.13E-06	5.44E-03	4.51E-06	1.07E-03
	Kidney	2.50E-04	2.85E-04	3.81E-08	5.99E-04	2.32E-04	1.72E-02	5.48E-05	3.60E-03
Adult	Wh. Bod	4.54E-05	5.17E-05	2.13E-09	5.70E-05	4.60E-03	5.44E-04	3.96E-08	8.59E-05
	Bone	7.67E-04	8.36E-04	8.01E-08	2.06E-03	4.60E-02	1.53E-02	4.61E-07	3.56E-04
	Liver	0.	0.	4.71E-09	1.17E-04	5.74E-06	4.37E-03	3.18E-06	7.56E-04
	Kidney	1.75E-04	1.99E-04	2.67E-08	5.65E-04	1.63E-04	1.23E-02	3.83E-05	2.52E-03

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*Adult whole body and bone dose conversion factors for Ra-226 have been obtained from Reference 1 and are based on applicable models and data from Reference 13. Ra-226 whole body and bone dose conversion factors for other age groups have been computed by assuming the same proportion to adult whole body and bone dose factors as given in Reference 11. All other dose conversion factors are from Reference 11 directly.

where d_{jk}(tot) is the total dose to organ j of an individual in age group k, from all exposure pathways, mrem/yr.

To evaluate compliance with 40 CFR 190 the staff has computed total doses to individuals using the above equation and all other models, data, and assumptions described in Appendix G, except that:

1) all dose contributions from radiation emitted by Rn-222, Po-218, Pb-214, Bi-214 and Po-214 have been eliminated; and

2) all dose contributions from radiation emitted by Pb-210, Bi-210, and Po-210, formed by decay of released Rn-222, have been eliminated.

With reference to Table G-3.1, the dose contributions eliminated, for the purpose of evaluating compliance with 40 CFR 190, include those due to any radiation emitted by: (1) isotopes for which i = 7, 8, 9, 10, or 11; and (2) isotopes present in particle size category p=5 (radon daughters).

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13. "Recommendations of the International Commission on Radiological Protection," ICRP Publication 10A, Pergamon Press, NY 1971.

APPENDIX G-6. DOSE CALCULATIONS FOR THE REGIONAL POPULATION

In this analysis cumulative doses to the population in the region of the model mill have been calculated using two fundamentally different methodologies. The first, and more conventional approach, is designed to yield population dose commitments resulting from a one-year exposure period. The results of this type of calculation are referred to here as "annual population dose commitments." The second calculational approach incorporates the concept of "environmental dose commitment" (Ref. 1) utilizing an integrating period of 100 years. In this approach, cumulative population doses resulting from a 100-year period of exposure, to environmental concentrations resulting from one year of radioactive releases, are calculated. The results of this calculational approach are referred to here as "annual environmental dose commitments".

In both approaches the site region is taken to be the area within 80 km (50 mi) of the model mill. Exposure pathways considered include all those evaluated for individuals.

1. ANNUAL POPULATION DOSE COMMITMENTS

Annual population dose commitments are calculated as the sum of the population doses resulting from a one-year perod of exposure to whatever environmental media concentrations exist during that exposure year. For this analysis, two such exposure years have been evaluated in terms of the resulting population dose commitments, i.e., the final year of actual milling and the fifth year after actual milling has ceased. The environmental media concentrations expected at these times are calculated using the models, equations, data, and assumptions described earlier in Appendix G-3.

1.1 Population Inhalation Doses

The population in the region of the model mill has been distributed over a grid formed by 16 radii extending outward from the model mill (bisecting the 16 compass directions, forming 22.5 degree wind sectors), and concentric circles drawn at various distances to 80 km (50 mi). In this fashion, the site region is broken up into segments, with each segment having its own population total. The procedure followed to calculate regional population dose totals for inhalation exposure is to: establish average individual doses within each segment, multiply these by the segment populations to determine the total segment population doses, and then sum over all segments to determine the regional population dose. The equations and dose conversion factors utilized to determine the average individual dose within each segment are as previously described in Appendix G-5. Average doses within each segment are determined along the segment centerline, at a distance midway between the inner and outer boundaries. The total regional population dose from inhalation of airborne radioactivity is determined by

$$M_j(\text{inh}) = 10^{-3} \sum_s P_s \, d_{js}(\text{inh}) \qquad (1)$$

where $d_{js}(\text{inh})$ is the average inhalation dose to organ j of individuals in segment s, mrem/yr;

$M_j(\text{inh})$ is the regional population inhalation dose to organ j, person-rem/yr;

P_s is the population residing in segment s, persons; and

10^{-3} is rem/mrem.

1.2 Population External Doses

Regional population doses resulting from external irradiation by radioactivity in the air and on ground surfaces are calculated using the same procedure as described above for inhalation doses. The segment-average external doses to individuals are determined using Equation 4 of Appendix G-5. Population doses from external pathways, over the entire model mill region, are obtained by

$$M_j(\text{ext}) = 10^{-3} \sum_s P_s \, d_{js}(\text{ext}) \qquad (2)$$

where d_{js}(ext) is the average external dose (including external doses from air and ground activity) to organ j of individuals in segment s, mrem/yr; and

M_j(ext) is the regional population external dose to organ j, person-rem/yr.

1.3 Population Ingestion Doses

Population doses resulting from ingestion of food products grown in the model mill region are calculated, initially, on the basis of the total mill-released radioactivity content of the annual food production. This yields the total ingestion population doses resulting from environmental contamination of the 80-km (50-mi) site region without regard for the geographical location of the actual dose receptor populations. For the model mill region, more food is assumed to be produced in the region than is required to feed the 0-80 km (0-50 mi) population. Therefore, total population doses based on the gross radioactivity content of the regional food production are in excess of the total ingestion doses that could be received by the population of the model mill region.

In order to estimate total radiological impacts, total population doses resulting from ingestion of the entire regional food production are first calculated on the basis of the gross activity content of the food produced. These total ingestion population doses are than multiplied by the fraction of the annual regional food production consumed by the regional population. The resulting reduced population doses are those received only by people actually residing in the model mill region, conservatively assuming that no vegetables, meat, or dairy products are imported from outside.

1.3.1 Total Ingestion Population Doses

For the model mill region average areal productivity factors for vegetables, meat, and dairy products have been assumed. These productivity factors have units of kg/yr-km^2 and are assumed to apply uniformly over the entire site region, from radial distances of 1 to 80 km (0.6 to 50 mi). No food is assumed to be grown within 1 km (0.6 mi) of the model mill.

For each food category, the general calculational procedure is as follows:

1) average activity concentrations are determined for each individual segment, based on concentrations calculated along the segment centerline, at a distance midway between the inner and outer boundaries;

2) segment-average concentration values are multiplied by the productivity factor (kg/yr-km^2) and by the segment area to determine the gross activity content of the vegetables, meat, or dairy products produced in that segment;

3) gross activity contents by segment are summed to obtain the regional totals;

4) ingestion population doses are computed for each age group (by accounting for the fractions of the various food types ingested by members of each age group, in accordance with the age distribution of the general population and appropriate age-specific ingestion rates); and

5) summing over the various age groups to obtain the total ingestion population doses.

For meat and milk segment-average concentration values are obtained directly from Equations 9 and 10 of Appendix G-3. Segment-average vegetable concentrations are first obtained separately for each vegetable type by using Equation 8 of Appendix G-3. Average vegetable concentrations, for each segment, are then obtained by

$$C_{vis}(\text{avg}) = \sum_v W_v C_{vis} \tag{3}$$

where C_{vis} is the concentration of isotope i in vegetable type v produced in segment s, pCi/kg;

C_{vis}(avg) is the concentration of isotope i, averaged over all types of vegetables, in segment s, pCi/kg; and

W_v is the weighting factor for vegetable type v, dimensionless.

Values of W_v have been selected to roughly correspond to the fractions of the three vegetable types in the average diet (see Table G-6.1). The value of W_v is assumed to be 0.78 for above ground vegetables, 0.20 for potatoes, and 0.02 for other below ground vegetables.

Table G-6.1. Average Consumption Rates of the Various Age Groups

Food Category	Average Consumption Rates, kg/yr[a]			
	Infants	Children	Teens	Adults
I. Vegetable Pathway				
A. Berries and Tree Fruit	0.	54.1	63.9	49.2
B. Fresh Vegetables[b]				
1. Potatoes	0.	27.2	42.3	60.4
2. Other root vegetables	0.	3.4	5.0	5.0
3. Leafy vegetables	0.	5.8	9.4	13.9
4. Other above ground vegetables	0.	11.4	19.5	26.0
C. Processed Vegetables				
1. Potatoes	0.	2.3	3.6	5.2
2. Other root vegetables	0.	0.9	1.4	1.4
3. Leafy vegetables	0.	0.4	0.6	0.8
4. Other above ground vegetables	0.	14.4	24.6	32.8
D. Grain, Rice, and Wheat	0.	118.2	136.2	90.8
TOTAL VEGETABLES:	0.	238.1	306.4	285.5
II. Meat Pathway				
A. Beef and Lamb[b]	0.	21.8	35.9	64.0
B. Fresh Pork[b]	0.	5.9	8.9	14.3
C. Poultry and Processed Pork	0.	21.0	33.2	49.6
TOTAL MEAT:	0.	48.7	78.0	127.9
III. Milk Pathway				
A. Fresh Milk[b]	207.6	207.6	246.0	129.6
B. Milk Products	0.	27.2	45.4	46.7
TOTAL MILK:	207.6	234.8	291.4	176.3

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[a] All data taken from Reference 3, and representative of average consumption rates by individuals at rural farm residences.

[b] These food categories evaluated for individual doses from ingestion pathways.

The gross activity content of isotope i, in food type f, produced over the entire model mill region is obtained by

$$Q_{fi} = \sum_{s} G_f A_s C_{fis} \qquad (4)$$

where A_s is the area of segment s, km²;

C_{fis} is the average concentration of isotope i, in food type f (vegetables, meat, or milk), in segment s, pCi/kg*;

G_f is the areal productivity factor for food type f, kg/yr-km²; and

Q_{fi} is the total activity content of isotope i in food type f produced in the region, pCi/yr.

Since ingestion dose conversion factors are age dependent, it is appropriate to consider the fractions of the various food types consumed by the different age groups. For this analysis the age distribution of the consuming population is assumed to be the same as that reflected by 1970 census data for the U.S. in general (Ref. 2). These data indicate that the general population is composed of 1.8 percent infants (0-year), 16.5 percent children (1-10 years), 19.6 percent teens (10-20 years), and 62.2 percent adults (20 years and up). These age fractions, and the

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*Milk concentrations are computed in units of pCi/liter and are assumed to have the same value in units of pCi/kg.

ingestion rates presented in Table G-6.1 enter into the following expression for determining the fraction of the produced food of type f consumed by members of age group k

$$F_{fk} = \frac{F_{pk}\, U_{fk}}{\sum\limits_{k} F_{pk}\, U_{fk}} \qquad (5)$$

where F_{fk} is the fraction of the production of food type f ingested by individuals in age group k, dimensionless (see Table G-6.2 for values used);

F_{pk} is the fraction of the population belonging to age group k, dimensionless; and

U_{fk} is the average ingestion rate of food type f for an individual in age group k, kg/yr.

Total population ingestion doses for each food type are calculated, using the results of Equations 4 and 5, by the following formula

$$M_{fj}(\text{ing}) = 10^{-3} \sum_{ik} E_f Q_{fi} F_{fk}\, DCF_{ijk}(\text{ing}) \qquad (6)$$

where $DCF_{ijk}(\text{ing})$ is the ingestion dose conversion factor for isotope i, organ j, and age group k, mrem/pCi (see Table G-5.4 for values);

E_f is a factor to account for the fraction of the gross activity content actually ingested, dimensionless;

$M_{fj}(\text{ing})$ is the total population dose to organ j resulting from ingestion of regionally produced food type f, person-rem/yr; and

10^{-3} is rem/mrem.

The value of the parameter E_f in the above equation is taken to be 1.0 for meat or milk products, and 0.5 for vegetables (to account for activity losses resulting from washing, peeling, boiling, etc.).

1.3.2 Regional Ingestion Population Doses

Equation 6, above, yields population doses resulting from total consumption of foods produced in the model region. However, the population of the model region is not of sufficient size to consume the entire regional food production. In order to compute the ingestion doses received by the population of the model region, the results of Equation 6 are multiplied by the ratios of the food requirements of the model region to the assumed food production. The annual requirement of food type f by the regional population is estimated by

$$FR_f = P \sum_{k} F_{pk} U_{kf} \qquad (7)$$

where FR_f is the annual requirement of food type f to feed the regional population, kg/yr; and

P is the total regional population.

The required ratio of the food requirement to the food production is obtained by

$$R_f = \frac{FR_f}{\sum\limits_{s} G_f A_s} \qquad (8)$$

where R_f is the ratio of the regional consumption of food type f to the regional production of food type f.

Using the data presented in Tables G-6.1 and G-6.2, the assumed regional food production rates, and Equations 7 and 8, the regional population is estimated to consume about 76.5%, 14.9%, and 25.2% of the regionally produced vegetables, meat, and milk, respectively.

2. ANNUAL ENVIRONMENTAL DOSE COMMITMENTS

A primary objective of the radiological impact analyses performed for this environmental statement is to estimate, with reasonable accuracy, the aggregate radiological impact of the model

Table G-6.2. Age Distribution of Population, Average and Per Capita Consumption Rates and Fractions

Age Group	Fraction of Population[a]	Average Total Consumption Rates, kg/yr[b]		
		Vegetables	Meat	Milk
Infants	0.0179	0.	0.	207.6
Children	0.1647	238.1	48.7	234.8
Teenagers	0.1957	306.4	78.0	291.4
Adults	0.6217	285.5	127.9	176.3
	Per Capita Average:[c]	276.7	102.8	209.0

Age Group	Fraction of Regional Production Ingested by Each Age Group		
	Vegetables	Meat	Milk
Infants	0.	0.	0.0178
Children	0.1418	0.0780	0.1850
Teenagers	0.2167	0.1485	0.2728
Adults	0.6415	0.7735	0.5244

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[a] Age fractions given reflect average values for the entire U.S. population indicated by 1970 census data, as reported in Reference 2.

[b] Consumption rates given are from Table G-6.1 and are not those used for, or appropriate to, the calculation of maximum individual doses.

[c] Per capita consumption rates shown are weighted averages over all age groups. They are used for determining the fractions of regional food production potentially consumed by the regional population.

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mill. To achieve this goal the concept of environmental dose commitment (EDC) is employed, utilizing an integrating period of 100 years. Under this calculational approach, the impacts of radioactivity releases over a one-year period are estimated by summing the resulting population dose commitments over an exposure period of 100 years following release.

The general calculational procedure conventionally employed in EDC estimation is as follows: assume that all evaluated releases occur instantaneously; establish time varying mathematical expressions for environmental media concentrations, population distributions, and agricultural productivities; and integrate over time as necessary to determine the resulting population dose commitments. The length of the integrating period is optional but a 100-year integrating period is frequently chosen.

A 100-year integrating period has been used to calculate regional environmental dose commitments for this analysis. Thus, residual environmental radioactivity concentrations present 100 years after the responsible releases, and any resulting additional population dose commitments, have not been taken into account. Also, the regional population, population distribution, and agricultural production rates have been assumed to remain at constant levels throughout the 100-year exposure period. The staff has elected to utilize a 100-year integrating period, rather than some longer time interval, primarily because: 1) the major exposure pathways are dominated by doses resulting from airborne activity concentrations which decrease rapidly when the source vanishes (the resuspension factor has a halflife of about 50 days); and 2) for a radionuclide in soil, a minimum of 75 percent of the infinite time integral of concentration occurs within the first 100 years (the mean lifetime of a non-decaying nuclide in soil is about 72 years, based on an environmental loss half-life of 50 years). For example, the 15-year EDC inhalation lung dose and ingestion bone dose have been computed to be 99.7 and 76.1 percent, respectively, of the values computed for a 100-year EDC time interval. Thus, over three fourths of the 100-year EDC for each year's releases occurs within the first 15 years, with exposure over the next 85 years contributing less than 25%. The staff estimates that the 100-year EDC's computed are within about 10 percent of those that would have otherwise been computed based on an infinite integrating period.

The staff has also elected to assume a constant population and constant food production rates. The effect of accounting for growth of the regional population, or regional food production, would be marginal increases in the calculated results. If such growth were assumed to be proportional to the projected population of the U.S. as given in Appendix G-8, regional population and agricultural production would increase by only about 14 percent over a 15-year period, during which over 76 percent of the 100-year EDC would be delivered. The 100-year increase in regional population, assuming constant relation to the U.S. population, would be about a third. The staff estimates the effect of accounting for such growth would be less than a 10 percent increase in the reported results, and does not consider this variation to be significant in view of the relative uncertainty of other portions of this analysis, and the initial hypothetical nature of the basic site parameters.

In order to calculate 100-year EDC's, based on constant agricultural and population data the value of the parameter t in Equations 2, 3, 4, and 6 is artificially set equal to 100.5 years. This yields environmental media concentrations equivalent to averages over the period from 100 to 101 years, resulting from constant release rates over the entire time. Exposure to these concentrations for a one-year period is, under the assumed conditions, numerically equivalent to exposure over the period from 0 to 101 years to environmental concentrations resulting from releases over the period from 0 to 1 year. To illustrate this equality, consider that exposure over the period from 100 to 101 years, to environmental concentrations resulting from constant releases over the entire time span, consists of exposure to concentrations resulting from releases during the discrete time intervals: t = 100 to 101 years (during the year of release); t = 99 to 100 years (average age of 1 year); t = 98 to 99 years (average age of 2 years);....... and t = 0 to 1 year (average age of 100 years). These component parts are identically the same as those comprising the integral to 100 years following release, of exposures to environmental media concentrations resulting from releases over a one-year period.

References

1. "Environmental Radiation Dose Commitment: An application to the Nuclear Power Industry", U.S. Environmental Protection Agency, EPA-520/4-73-002, 1974.

2. "Environmental Analysis of the Uranium Fuel Cycle, Part II - Nuclear Power Reactors," U.S. Environmental Protection Agency, EPA-520/9-73-003-C, November, 1973.

3. J. F. Fletcher and W. L. Dotson (compilers), "HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Industry," Hanford Engineering Development Laboratory, HEDL-TME-71-168, December 1971.

APPENDIX G-7. HEALTH EFFECTS FROM IRRADIATION

In this document, health effects which could be attributed to radiation dose commitments associated with uranium milling activity are estimated. These health effects are classified into two general types: somatic and genetic. The number of health effects is determined by multiplying the dose commitment by an appropriate risk estimator. In this appendix the risk estimators which have been used in the document are presented, and their derivation is discussed.

1. BACKGROUND

Health effects have been calculated in other NRC reports, such as WASH-1400[1] and GESMO.[2] In both, data were used, with a few changes, from the BEIR Report as a basis for calculating a range of health effects.[3] Risks are given as either "absolute" or "relative." Relative risk is defined as "the ratio of the risk in those exposed to the risk to those not exposed (incidence in exposed populations to incidence in control populations)" (Ref. 3, p. 216). Absolute risk is defined as the "product of assumed risk times the total population at risk, the numbers of cases that will result from exposure of a given population" (Ref. 3, p. 213).

In the BEIR Report, health effects were calculated for four basic cases: (1) an absolute risk model with a 30-year plateau; (2) an absolute risk model with a lifetime plateau; (3) a relative risk model with a 30-year plateau; and (4) a relative risk model with a lifetime plateau. Since the mechanisms of radiation carcinogenesis may be different for different organs, no one method for calculating health effects from whole body exposure was endorsed in the BEIR Report.

Since the publication of the above reports, a National Academy of Sciences Ad Hoc Committee (NAS) has issued a report entitled "Health Effects of Alpha-Emitting Particles in the Respiratory Tract."[4] This recent NAS report suggested two changes in the conclusions of the BEIR Report that are important to this document. First, it was stated that the absolute risk coefficient for lung mortalities should be increased from 1.3 to 2 mortalities/yr/10^6 person-rem. This finding was based on new data on U. S. uranium miners exposed to radon. Second, it was stated that the relative risk method of assessing radiological risks might be more appropriate for estimating lung cancer risks in human populations. This finding was based in part on lung tumor mortality data of beagles exposed to alpha irradiation. It was indicated in a recent paper by Land and Norman that the relative risk approach is consistent with human data on lung cancer.[5] Since the majority of health effects associated with uranium milling were expected to be from inhalation of radon (an alpha emitter), these findings were particularly significant for this document.

Although health effects from radiation have been studied more thoroughly than health effects from many other carcinogenic agents, there are still many uncertainties in the estimation of health effects from irradiation, as well as uncertainties associated with other carcinogenic agents. These uncertainties are in part due to the similarity of health effects from chronic irradiation to naturally occurring health effects. Typically, long latency periods and very low probabilities of occurrence make it difficult to detect any increase in cancers associated with chronic exposure to low levels of radiation. The approach taken in developing risk estimators for this document has been to place conservative bounds on health effects from the U.S. uranium milling industry. It is expected that the assumptions and methods for computing health effects from irradiation will change as more data, such as the National Academy of Sciences BEIR III Report, which is to be published in 1979, become available.

2. SOMATIC RISK ESTIMATORS

Somatic risk estimators were calculated for cancers of the lung and bone, leukemia, and for whole body exposure. The risk estimators for all cancers except bone were calculated as the average of the absolute and relative models. In deriving the different risk estimators, it was assumed that under equilibrium conditions of continuous exposure, the number of deaths per lifetime per 10^6 man-rem was equal to the number of deaths per year per 10^6 man-rem per year. A central value and a range of risk estimators for each type of cancer are given in Table G-7.1. Conservative upper and lower bounds on risk estimators are also given. Assumptions and sources of data for each risk estimator are described below.

Table G-7.1. Somatic Risk Estimators

Type of Cancer	Central Value (premature deaths/lifetime/ 10^6 man-rem)	Range (premature deaths/lifetime/ 10^6 man-rem)
Lung	7.2×10^1	$3.0 \times 10^1 - 1.5 \times 10^2$
Bone	6	5 - 8
Leukemia	3.2×10^1	$2.6 \times 10^1 - 3.7 \times 10^1$
Other	1.2×10^2	$3.9 \times 10^1 - 3.1 \times 10^2$
TOTAL	2.3×10^2	$1.0 \times 10^2 - 5.1 \times 10^2$

2.1 Lung

A risk estimator for premature death due to lung cancer was developed based primarily on data from four sources: (1) the BEIR Report;[3] (2) "Health Effects of Alpha-Emitting Particles in the Respiratory Tract;"[4] (3) "Vital Statistics of the United States 1970, Vol. II--Mortality;"[6] and (4) "Exposure to Radon Daughters and the Incidence of Lung Cancer."[7]

A methodology similar to that used in BEIR (pp. 172, 173) was used in developing risk estimators for lung cancer. Estimates of the annual number of premature lung cancer deaths from continuous exposure of 10^7 persons to 0.1 rem/yr, using the absolute and relative risk models, are given in Tables G-7.2 and G-7.3, respectively. Four risk estimators (in units of premature deaths due to

Table G-7.2. Estimate of Annual Number of Premature Lung Cancer Deaths from Continuous Exposure of 10^7 Persons to 0.1 rem/yr, Using Absolute Risk Model

		Premature Deaths[b] due to Irradiation During:				Total Premature Deaths[b]	
Age Cohort	Population[a] Fraction	0-9yrs (c)	0-9yrs (d)	10+yrs (c)	10+yrs (d)	(c)	(d)
0-9	0.183	-	-	-	-	-	-
10-19	0.196	0.47	0.47	-	-	0.47	0.47
20-29	0.147	2.59	2.59	0.35	0.35	2.94	2.94
30-39	0.111	2.22	2.22	2.22	2.22	4.44	4.44
40-49	0.119	2.09	2.38	4.76	4.76	6.85	7.14
50-59	0.104	0.25	2.08	5.99	6.24	6.24	8.32
60-69	0.077	-	1.54	4.62	6.16	4.62	7.70
70-79	0.046	-	0.92	2.76	4.60	2.76	5.52
80+	0.019	-	0.38	1.14	2.28	1.14	2.66
Total	1.00	7.62	12.58	21.84	26.61	29.46	39.19

[a] U.S. population for 1970.

[b] These numbers are in terms of premature deaths/yr/10^6 man-rem/yr. Under equilibrium conditions of continuous exposure, premature deaths/yr/10^6 man-rem/yr are equal to premature deaths/lifetime/10^6 man-rem to the general population.

[c] 30-year plateau.

[d] Lifetime plateau.

Table G-7.3. Estimate of Annual Number of Premature Lung Cancer Deaths from Continuous Exposure of 10^7 Persons to 0.1 rem/yr, Using Relative Risk Model

Age Cohort	Natural Incidence of Lung Cancer[a] (cancers/yr/10^7 in population)	Premature Deaths due to Irradiation During: 0-9yrs (c)	0-9yrs (d)	10+yrs (c)	10+yrs (d)	Total Premature Deaths[b] (c)	(d)
0-9	1	-	-	-	-	-	-
10-19	1	0.00	0.00	-	-	0.00	0.00
20-29	5	0.09	0.09	0.00	0.00	0.09	0.09
30-39	44	0.88	0.88	0.26	0.26	1.14	1.14
40-49	295	5.16	5.90	3.54	3.54	8.70	9.44
50-59	831	2.08	16.62	14.29	14.96	16.37	31.58
60-69	1172	-	23.44	21.10	28.13	21.10	51.57
70-79	846	-	16.92	15.23	25.38	15.23	42.30
80+	258	-	5.16	4.64	10.06	4.64	15.22
Total	3453	8.21	69.01	59.06	82.33	67.27	151.34

[a] Calculated from data in "Vital Statistics of the United States 1970, Volume II - Mortality, Part A," U. S. Dept. of Health, Education, and Welfare, pp. 1-10, 11; 6-17, 1974.

[b] These number are in terms of premature deaths/yr/10^6 man-rem/yr. Under equilibrium conditions of continuous exposure, premature deaths/yr/10^6 man-rem/yr are equal to premature deaths/lifetime/10^6 man-rem to the general population.

[c] 30-year plateau.

[d] Lifetime plateau.

lung cancer/lifetime/10^6 man-rem) for lung exposure were calculated: (1) an absolute model with a 30-year plateau (3.0×10^1); (2) an absolute model with a lifetime plateau (3.9×10^1); (3) a relative model with a 30-year plateau (6.7×10^1); and (4) a relative model with a lifetime plateau (1.5×10^2). A central value for premature death due to lung cancer was obtained by averaging the above values. This central value is 7.2×10^1 premature deaths/lifetime/10^6 man-rem or 3.6×10^2 premature deaths/lifetime/10^6 man-WLM. Lung cancers due to the inhalation of radon daughters were calculated directly from the dose to the lung in terms of Working Level Months (WLM).

Risk estimators for lung cancer are presented in terms of man-rem so that the units of risk of premature death due to lung cancer are consistent with the units of risk for other types of cancer. A factor of 5 rem/WLM was used in converting between exposures in WLM and exposures in rem.[3,4] Assumptions for each model are listed in Table G-7.4.

2.2 Bone

A risk estimator for death due to bone cancer was developed based on data from WASH 1400, and BEIR. Since the natural incidence of bone cancer is small compared with cancer of other organs, risk estimators based on the relative risk method were not calculated. A methodology similar to that used in BEIR (p. 173) was used in developing absolute risk estimators for bone cancer. Estimates of the annual number of premature bone cancer deaths from continuous exposure of 10^7 persons to 0.1 rem/yr, using the absolute risk model, are given in Table G-7.5.

Table G-7.4. Assumptions in Calculating Risk Estimators for Lung and Bone Cancer

Type of Cancer	Age at Time of Irradiation	Latency Period[a] (yrs)	Risk Coefficients: Absolute[b] (premature deaths/yr/10^6 man-rem)	Risk Coefficients: Relative[c] (percent increase in premature deaths/lifetime/WLM)
Lung	0-9.9	15	2.0[d]	10.0
	10+	15	2.0[d]	3.0
Bone	In Utero	0	0.4	-
	0-19.9	10	0.4	-
	20+	10	0.2	-

[a] Latency periods were taken from "The Effect on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences (1972), for lung cancer, and from "Reactor Safety Study, an Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants," WASH-1400, NUREG-75/014 (1975) for bone.

[b] Absolute risk coefficients for lung cancer for adults and for bone cancer for the 0+ age groups were obtained from, respectively, "Health Effects of Alpha-Emitting Particles in the Respiratory Tract," Report of the Ad Hoc Committee on "Hot Particles" of the Advisory Committee on Biological Effects of Ionizing Radiations, National Academy of Sciences (1976), and "Reactor Safety Study, an Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants," WASH-1400, NUREG-75/014 (1975). Since there is not a great deal of information on lung cancer due to exposure to children or on bone cancer due to in utero exposure, the same absolute risk coefficients were assumed for these groups as for the next older groups.

[c] The relative risk coefficient for lung cancer for adults was selected based on data in W. H. Ellett, "Exposure to Radon Daughters and the Incidence of Lung Cancer" 1 December 1977. In that document, lung cancers were calculated for two cases, one of which assumed a relative risk coefficient of a 9% increase in lung cancers per WLM for children. Since there is a great deal of uncertainty about the relative risk coefficient for children, that coefficient was rounded off to a 10% increase in lung cancers per WLM for this document.

[d] These absolute risk coefficients correspond to 10 premature deaths/yr/10^6 man-WLM.

Two absolute risk estimators for bone irradiation were calculated (in units of premature deaths due to bone cancer/lifetime/10^6 man-rem): (1) an absolute model with a 30-year plateau (5.2); and (2) an absolute model with a lifetime plateau (7.7). A central value for bone cancer was obtained by averaging the values for the 30-year plateau and the lifetime plateau. The central value for death due to bone cancer is six premature deaths/lifetime/10^6 man-rem. Assumptions for each model are listed in Table G-7.4.

2.3 Leukemia

A risk estimator for leukemia was derived from Table 3-3 and Table 3-4 of the BEIR Report (pp. 172-173). An absolute risk estimator of 2.6×10^1 and a relative risk estimator of 3.7×10^1 premature deaths due to leukemia/lifetime/10^6 man-rem were derived from BEIR. The risk estimator for leukemia used in this document was the average of the absolute and the relative risk estimators. This average value is 3.2×10^1 premature deaths due to leukemia/lifetime/10^6 man-rem.

2.4 Whole Body

Risk estimators for whole body exposure were derived from Tables 3-3 and 3-4 of BEIR (pp. 172-173) and adjusted with more recent lung risk coefficients. Four risk estimators (in units of premature deaths/lifetime/10^6 man-rem) for whole body exposure were calculated: (1) an absolute model with a 30-year plateau (1.0×10^2); (2) an absolute model with a lifetime plateau (1.1×10^2); (3) a relative model with a 30-year plateau (1.9×10^2); and (4) a relative model

Table G-7.5. Estimate of Annual Number of Premature Bone Cancer Deaths from Continuous Exposure of 10^7 Persons to 0.1 rem/yr, Using Absolute Risk Model

Age Cohort	Population[a] Fraction	Premature Deaths[b] due to Irradiation During:					Total Premature Deaths[b]	
		In Utero	0-19yrs (c)	0-19yrs (d)	20+yrs (c)	20+yrs (d)	(c)	(d)
0-9	0.183	0.06	-	-	-	-	0.06	0.06
10-19	0.196	-	0.30	0.30	-	-	0.30	0.30
20-29	0.147	-	0.88	0.88	0.04	0.04	0.92	0.92
30-39	0.111	-	0.89	0.89	0.22	0.22	1.11	1.11
40-49	0.119	-	0.71	0.95	0.48	0.48	1.19	1.43
50-59	0.104	-	0.16	0.83	0.60	0.62	0.76	1.45
60-69	0.077	-	-	0.62	0.46	0.62	0.46	1.24
70-79	0.046	-	-	0.37	0.28	0.46	0.28	0.83
80+	0.019	-	-	0.15	0.11	0.23	0.11	0.38
Total	1.00	0.06	2.94	4.99	2.19	2.67	5.19	7.72

[a] U. S. Population for 1970.

[b] These numbers are in terms of premature deaths/yr/10^6 man-rem/yr. Under equilibrium conditions of continuous exposure, premature deaths/yr/10^6 man-rem/yr are equal to premature deaths/lifetime/10^6 man-rem to the general population.

[c] 30-year plateau.

[d] Lifetime plateau.

with a lifetime plateau (5.1×10^2). The risk estimator for whole body exposure used in this document was the average of the above risk estimators (2.3×10^2 premature deaths/ lifetime/10^6 man-rem).

2.5 Other

The risk estimator for all other cancers was calculated by subtracting the risk estimators for lung, bone, and leukemia from the risk estimator for whole-body exposure. The central value for the risk of death from other cancers is 1.2×10^2 premature deaths/lifetime/10^6 man-rem.

2.6 Life-Shortening

The majority of the somatic health effects calculated in this document (see Section 6.4) are due to premature death due to lung cancer. Premature death can also be evaluated in terms of life-shortening. Life-shortening is calculated by multiplying the total number of premature deaths in an age cohort (columns (c) and (d) of Tables G-7.2 and G-7.3 for lung cancer) by the life expectancy for the cohorts. Life expectancies were taken from reference (6). The average number of years lost per premature death for the different risk models for premature deaths due to lung cancer is as follows: (1) absolute model with a 30-year plateau (27 years lost/premature death); (2) absolute model with a lifetime plateau (24 years lost/premature death); (3) relative model with a 30-year plateau (18 years lost/premature death); and (4) relative model with a liftetime plateau (16 years lost/premature death). The average number of years lost per million person rem is 6700 years lost or about 19 years lost/premature death. Since about 70% of the North American continental health effects (Table 6.39) are due to lung cancer, 19 years lost per premature death was used as an approximation in converting premature deaths to years lost.

3. GENETIC RISK ESTIMATORS

Genetic risk estimators for this document were taken from GESMO.[2] The GESMO genetic risk estimators were based on the geometric mean of the range of values given in Table 4 of BEIR (p. 57). The following genetic risk estimators were used: risk of specific genetic defects (158 occurrences/lifetime/10^6 man-rem); risk of defects with complex etiology (100 occurrences/lifetime/10^6 man-rem); total genetic defect risk (258 occurrences/lifetime/10^6 man-rem). A range of uncertainty extends a factor of 3.16 above and below this for specific genetic defects and a factor of 10 for defects with complex etiology.

References

1. "Reactor Safety Study, an Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, 1975.

2. "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," U.S. Nuclear Regulatory Commission, NUREG-0002, August 1976.

3. "The Effect on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, 1972.

4. "Health Effects of Alpha-Emitting Particles in the Respiratory Tract," Report of the Ad Hoc Committee on "Hot Particles" of the Advisory Committee on the Biological Effects of Ionizing Radiations, National Academy of Sciences, 1976.

5. C. E. Land and J. E. Norman, "The Latent Periods of Radiogenic Cancers Occurring Among Japanese A-Bomb Survivors," International Atomic Energy Agency Symposium on the Late Biological Effects of Ionizing Radiation, Vienna, Austria, 13-17 March 1978.

6. "Vital Statistics of the United States 1970, Volume II - Mortality, Part A," U.S. Dept. of Health, Education and Welfare, pp. 1-10, 1-11, 6-17, 1974.

7. W. H. Ellett, "Exposure to Radon Daughters and the Incidence of Lung Cancer," American Nuclear Society Meeting, December 1, 1977, San Francisco, California.

APPENDIX G-8. CONTINENTAL RADIOLOGICAL IMPACTS

Table G-8.1. Population Exposures and Doses from Inhalation of Radon-222 Daughter Products in 1978[a]

Location of Release	Population Exposure per kCi Rn-222[b] Released					
	Man-pCi/m³			Organ-rem (lung)		
	U.S.	Canada	Mexico	U.S.	Canada	Mexico
Casper, Wyoming	8.3 E4[c]	3.2 E3	3.7 E3	52	2.0	2.3
Falls City, Texas	10.8 E4	1.2 E3	5.2 E3	68	0.8	3.2
Grants, New Mexico	7.0 E4	1.0 E3	11.3 E3	44	0.6	7.1
Wellpinit, Washington	6.0 E4	7.0 E3	1.6 E3	38	4.4	1.0

[a] Modified from NUREG/CR-0573.

[b] Unit release is 1 kCi Rn-222/yr and excludes exposures within 50 miles of the release point. Regional population exposures are discussed in Section 6.4.2.

[c] Notation: 8.3 E4 = 8.3 × 10^4.

Table G-8.2. Population Exposures and Doses to the Population of the United States from Inhalation of Lead-210 and Polonium-210 in 1978[a]

Release site	Population Exposure and Dose per kCi Rn-222 Released in 1978			
			Organ-rem	
	Man-pCi/m³	Man-rem Whole Body	Lung	Bone
Casper, Wyoming	25.3			
Primary dose in 1978		1.8	1.2	23.8
Resuspension dose		0.4	0.6	4.5
Total dose		2.2	1.8	28.3
Falls City, Texas	22.2			
Primary dose in 1978		1.5	1.0	20.9
Resuspension dose		0.4	0.5	4.0
Total dose		1.9	1.5	24.9
Grants, New Mexico	20.7			
Primary dose in 1978		1.4	1.0	19.5
Resuspension dose		0.2	0.5	3.7
Total dose		1.6	1.5	23.2
Wellpinit, Washington	21.5			
Primary dose in 1978		1.5	1.0	20.3
Resuspension dose		0.4	0.5	3.8
Total dose		1.9	1.5	24.1

[a] Modified from NUREG/CR-0573. Population exposures and doses within 50 miles of the release site are not included.

Table G-8.3. Population Exposures and Doses to the Population of Canada from Inhalation of Lead-210 and Polonium-210 in 1978[a]

		Population Exposure and Dose per kCi Rn-222 Released in 1978		
		Man-rem	Organ-rem	
Release Site	Man-pCi/m^3	Whole Body	Lung	Bone
Casper, Wyoming	1.2			
Primary dose in 1978		8.5 E-2[b]	5.7 E-2	11.3 E-1
Resuspension dose		1.7 E-2	2.7 E-2	2.1 E-1
Total dose		10.2 E-2	8.4 E-2	13.4 E-1
Falls City, Texas	0.4			
Primary dose in 1978		2.8 E-2	1.9 E-2	3.7 E-1
Resuspension dose		0.6 E-2	0.9 E-2	0.7 E-1
Total dose		3.4 E-2	2.8 E-2	4.4 E-1
Grants, New Mexico	0.5			
Primary dose in 1978		3.5 E-2	2.4 E-2	4.7 E-1
Resuspension dose		0.7 E-2	1.1 E-2	0.9 E-1
Total dose		4.2 E-2	3.5 E-2	5.6 E-1
Wellpinit, Washington	1.7			
Primary dose		12.0 E-2	8.0 E-2	16.0 E-1
Resuspension dose		2.4 E-2	3.8 E-2	3.0 E-1
Total dose		14.4 E-2	11.8 E-2	19.0 E-1

[a] Modified from NUREG/CR-0573.

[b] Notation: 8.5 E-2 = 8.5 × 10^{-2}.

Table G-8.4. Population Exposures and Doses to the Population of Mexico from Inhalation of Lead-210 and Polonium-210 in 1978[a]

		Population Exposure and Dose per kCi Rn-222 Released in 1978		
		Man-rem	Organ-rem	
Release Site	Man-pCi/m^3	Whole Body	Lung	Bone
Casper, Wyoming	1.3			
Primary dose in 1978		9.2 E-2[b]	6.1 E-2	1.2 E0
Resuspension dose		1.8 E-2	2.9 E-2	2.0 E-1
Total dose		11.0 E-2	9.0 E-2	1.4 E0
Falls City, Texas	1.1			
Primary dose in 1978		7.8 E-2	5.2 E-2	1.2 E0
Resuspension dose		1.5 E-2	2.5 E-2	2.0 E-1
Total dose		9.3 E-2	7.7 E-2	1.4 E0
Grants, New Mexico	3.4			
Primary dose in 1978		24.2 E-2	16.0 E-2	3.1 E0
Resuspension dose		4.7 E-2	7.7 E-2	6.0 E-1
Total dose		28.9 E-2	23.7 E-2	3.7 E0
Wellpinit, Washington	0.7			
Primary dose in 1978		5.0 E-2	3.3 E-2	7.0 E-1
Resuspension dose		0.9 E-2	1.6 E-2	1.0 E-1
Total dose		5.9 E-2	4.9 E-2	8.0 E-1

[a] Modified from NUREG/CR-0573.

[b] Notation: 9.2 E-2 = 9.2 × 10^{-2}.

Table G-8.5. Inhalation Dose Conversion Factors Used in Calculation of Continental Health Effects[a]

	Conversion Factors (mrem/yr)/(pCi/m^3)	
Organ	Pb-210	Po-210
Pulmonary lung	4.7 E1[b]	3.4 E2
Whole body	7.1 E1	8.6 E0
Bone	9.4 E2	3.4 E0

[a] Modified from NUREG/CR-0573.

[b] Notation: 4.7 E1 = 4.7 × 10^1.

Table G-8.6. Population Exposure and 50-Year Dose Commitment to the Population of the United States from Ingestion of Lead-210 Released in 1978[a]

	Exposure and Dose per kCi Rn-222 Released		
Release Site	Man-pCi	Man-rem Whole Body	Organ-rem Bone
1978			
Casper, WY	7.2 E5[b]	2.7 E0	3.74 E1
Falls City, TX	3.9 E5	1.5 E0	2.03 E1
Grants, NM	6.3 E5	2.4 E0	3.28 E1
Wellpinit, WA	8.1 E5	3.1 E0	4.21 E1
1979			
Casper, WY	2.24 E4	8.5 E-2	1.2 E0
Falls City, TX	1.23 E4	4.7 E-2	6.0 E-1
Grants, NM	2.14 E4	8.1 E-2	1.1 E0
Wellpinit, WA	2.16 E4	8.2 E-2	1.1 E0

[a] Modified from NUREG/CR-0573. Population exposures and doses within 50 miles of the release site are not included.

[b] Notation: 7.2 E5 = 7.2 × 10^5.

Table G-8.7. Population Exposure and 50-Year Dose Commitment to the Population of Canada from Ingestion of Lead-210 Released in 1978[a]

	Exposure and Dose per kCi Rn-222 Released		
Release Site	Man-pCi	Man-rem Whole Body	Organ-rem Bone
1978			
Casper, WY	2.2 E4[b]	8.4 E-2	1.1 E0
Falls City, TX	9.2 E3	3.5 E-2	4.8 E-1
Grants, NM	1.3 E4	4.9 E-2	6.8 E-1
Wellpinit, WA	7.0 E4	2.7 E-1	3.6 E0
1979			
Casper, WY	7.59 E2	2.9 E-3	4.0 E-2
Falls City, TX	2.42 E2	9.2 E-4	1.3 E-2
Grants, NM	3.80 E2	1.4 E-3	2.0 E-2
Wellpinit, WA	2.31 E3	8.8 E-3	1.2 E-1

[a] Modified from NUREG/CR-0573.

[b] Notation: 2.2 E4 = 2.2 × 10^4.

Table G-8.8. Population Exposure and 50-Year Dose Commitment to the Population of Mexico from Ingestion of Lead-210 Released in 1978[a]

	Exposure and Dose per kCi Rn-222 Released		
Release Site	Man-pCi	Man-rem Whole Body	Organ-rem Bone
1978			
Casper, WY	4.9 E4[b]	1.9 E-1	2.5 E0
Falls City, TX	6.2 E4	2.4 E-1	3.2 E0
Grants, NM	9.6 E4	3.6 E-1	5.0 E0
Wellpinit, WA	3.2 E4	1.2 E-1	1.7 E0
1979			
Casper, WY	1.64 E3	6.2 E-3	8.5 E-2
Falls City, TX	1.98 E3	7.5 E-3	1.0 E-1
Grants, NM	2.93 E3	1.1 E-2	1.5 E-1
Wellpinit, WA	1.03 E3	3.9 E-3	5.4 E-2

[a] Modified from NUREG/CR-0573.

[b] Notation: 4.9 E4 = 4.9 × 10^4.

Table 8.9. Projected Populations of the United States, Canada, and Mexico, 1978-2000 (in millions)

Year	U.S. (Series II)(a)	Canada (Projections)(b)	Mexico (Series B)(c)
1978	218.4	23.3	65.8
1979	220.2	23.5	68.0
1980	222.2	23.8	70.3
1981	224.2	24.0	72.6
1982	226.3	24.3	75.0
1983	228.5	24.6	77.5
1984	230.7	24.9	80.0
1985	232.9	25.1	82.6
1986	235.1	25.4	85.3
1987	237.2	25.6	88.0
1988	239.4	25.9	90.8
1989	241.5	26.1	93.6
1990	243.5	26.4	96.5
1991	245.5	26.6	99.5
1992	247.4	26.8	102.5
1993	249.3	27.0	105.5
1994	251.1	27.2	108.6
1995	252.8	27.4	111.7
1996	254.4	27.6	114.9
1997	255.9	27.7	118.0
1998	257.5	27.9	121.3
1999	258.9	28.0	124.5
2000	260.4	28.2	127.8

[a] U.S. Bureau of the Census, 1977.

[b] Statistics Canada, 1974.

[c] Unpublished data, U.S. Bureau of the Census, 1977.

Table 8.10. Projections of United States, Canadian, and Mexican Populations, in 25-Year Intervals between 2000 and 2100 (in millions)[a,b]

Year	U.S. (Series II)	Canada (Projection C)	Mexico (Series B)
2000	260.4	28.2	127.8
2025	287.5	31.1	141.1
2050	291.1	31.5	142.9
2075	291.9	31.6	143.3
2100	293.0	31.7	143.8

[a] Assumes growth rate for each nation is equivalent to that reported for North America in "Development of the Methodology Relevant to U.N. Global Projections," paper presented to the Ad Hoc Group of Experts on Demographic Projection, U.N. Fund for Public Activities, Population Division, New York, 7-11. November 1977.

[b] Projections for the year 2000 taken from Table G-8.9.

APPENDIX G-9. OVERVIEW OF URANIUM MILL RESEARCH ACTIVITIES

By necessity, the radiological impacts of uranium-milling operations are assessed primarily by calculating the potential radiation exposures resulting from these operations. These calculations are carried out using input parameters and data regarding release rates and environmental transport mechanisms, which, for the most part, have been developed over the last several years through government-sponsored research and technical assistance efforts. The purpose of this appendix is to provide an overview of the various research efforts upon which the staff has relied in the preparation of this document, and to illustrate, qualitatively, how the results have been used.

Several reports have described the sources of radioactivity and radioactive material released in and around a uranium mill, the pathways of the released material to people living in the vicinity of the mill, and doses received by these people.[1-5] The source terms and pathways are well defined in a qualitative manner. The reports cited, although among the earliest to appear on the subject, also assigned quantitative values to the source terms and pathway transfer parameters; these quantitative values, however, were often based on rough estimates and assumptions since relatively few actual measurements for the source terms and transfer parameters had then been made and documented in the literature.

In view of this shortage of documented technical data about radioactivity emissions from uranium mills, the Nuclear Regulatory Commission (NRC) has, since 1977, supported long-term field studies at operating mills to measure both effluent release rates, resulting environmental concentrations, and dose rates. It was anticipated that the field studies would provide useful information in three important areas:

1) Radiological Assessment of Uranium Mills--information for use in both this generic statement on uranium milling, and environmental impact statements for individual mills.

2) Regulatory Guides on Effluents, and Environmental Monitoring for Uranium Mills--information on the types of measurements that should be made and how they should be made.

3) Compliance with EPA's Environmental Standards for the Uranium Fuel Cycle--information and data from which to assess uranium mills' compliance with EPA standards.

The specific objectives of the environmental field study program at operating uranium facilities have included:

1) providing measurements that could be used as a basis for estimating and characterizing airborne-effluent release rates (source terms) for uranium milling activities, e.g., release rates of radioactive particulates (specific nuclides) and radon-222 from mill stacks and vents, ore piles, and tailings piles

2) providing data that could be used to confirm predicted offsite environmental concentrations or that could form the data base for revising estimates of release rates

3) evaluating the potential radiological significance of food-ingestion pathways resulting from airborne-effluent releases

4) testing, demonstrating, and evaluating environmental monitoring methods and techniques in order to provide guidance for monitoring programs

A task force to guide the overall program was appointed in 1976. Field and laboratory studies including measurements were conducted from 1977 through 1979. Organizations engaged through the NRC to conduct the studies have included:

1) Argonne National Laboratory, Argonne, IL
2) Battelle Pacific Northwest Laboratory, Richland, WA
3) Oak Ridge National Laboratory, Oak Ridge, TN
4) Ford, Bacon and Davis Utah, Inc., Salt Lake City, UT
5) USEPA, Las Vegas, NV

Cooperative agreements were reached between these research organizations and the operating uranium mills. The tests were conducted with full industry approval and cooperation and, in many cases, with active participation of mill personnel. Without this cooperation, the success of the studies could have been very limited. The following uranium mills participated in these studies:

1) Anaconda, Bluewater, NM
2) Kerr-McGee, Ambrosia Lake, NM
3) Sohio, Seboyeta, NM
4) United Nuclear Churchrock, Gallup, NM
5) United Nuclear - Homestake Partners, Milan, NM
6) Union Carbide, Uravan, CO
7) Exxon, Douglas, WY

The field studies undertaken and completed have been appropriately documented in formal reports and results have been incorporated, to the extent appropriate, into this Final Generic Environmental Impact Statement on Uranium Milling (GEIS). This appendix summarizes the formal reports prepared to date. The summaries include the types of measurements made and the length and duration of measurements, identify the mills involved in the studies, and present the general nature of the results.

The reports reviewed for this appendix are those included herein as References 6-9, 12, 13, 19, 26, 27, 30, 34, and 36, as well as:

1) C.W. Fort, et al., "Radioactive Emissions from Yellowcake Processing Stacks at Uranium Mills," U.S. Environmental Protection Agency, 1980.

2) G. A. Sehmel, "Airborne Particulate Concentrations and Fluxes at an Active Uranium Mill Tailings Site" *in* Management Stabilization and Environmental Impact of Uranium Mill Tailings, Proceedings of the NEA Seminar, Organization for Economic Cooperation and Development, Albuquerque, NM, July 1979.

3) M.H. Momeni, et al., "Radiological and Environmental Studies at Uranium Mills: A Comparison of Theoretical and Experimental Data" *in* Management Stabilization and Environmental Impact of Uranium Mill Tailings, Proceedings of the NEA Seminar, Organization for Economic Cooperation and Development, Albuquerque, NM, July 1979.

1. ORE PAD AND GRINDING

1.1 Particulates

Because of the radioactivity involved, uranium mining and milling present a potential radiation-induced health hazard. Release of radioactive airborne particles (principally the uranium-238 series) causes human exposure through the pathways of inhalation, ingestion and external irradiation. Food grown on contaminated ground or in contact with contaminated water might contain radioactive particulates.

As part of the field-study program to characterize and establish airborne concentration levels of U-238, Th-230, Ra-226, and Pb-210, Argonne National Laboratory reported measurements made in the vicinity of the Anaconda Uranium Mill, Bluewater, NM.^{6} Site-specific climatological and meteorological factors were assessed. Measured airborne concentrations of radioactive particles were compared to natural background levels and to maximum permissible concentrations.

Airborne particles were collected at three stations for about two-thirds of a year using a continuous air collection method at a sampling rate of 10 L/min; also, particles were measured in monthly composites collected periodically at four stations using "high volume" air samplers at a flow rate of 1400 L/min. The ratios of concentrations of each radionuclide to the concentrations of U-238 indicated that the concentrations of the radionuclides were influenced principally by the proximity of the major sources of emission and the direction of the wind. The concentration of Pb-210 exceeded that of U-238 in all cases. The ratio of Pb-210/U-238 was 12.3 and 13.3 for stations dominated by the emissions from the tailings and ore pads, but was only 1.6 for the station dominated by the yellowcake stack emission. The ratio of the radionuclide concentrations measured by the two methods of air sample collection (i.e., continuous method and high-volume method) was between 0.8 and 1.2 for uranium, radium, and lead at one station, but was between 0.28 to 1.7 for thorium, radium, and lead at two other stations. The average concentrations calculated from the measurements made in this study suggested that releases from the Anaconda mill were well within the existing limits of 10 CFR Part 20.

1.2 Radon

Major sources of radon at uranium mills are 1) the ore pad, where ore is stored for blending and feeding to the mill, 2) crushing and grinding of the ore to maximize the uranium extraction; and

3) the tailings retention area. The rate of radon release from each source is dependent on the control procedures that are used.

In an extensive study of radon and radon-daughter concentrations at the Anaconda Uranium Mill, working level (WL), (see Appendix G-5) and meteorological variables were measured continuously from June 1977 through June 1978 at three field stations with measurements integrating to hourly intervals.[7] These studies served as a means to test, demonstrate, and evaluate environmental monitoring methods and techniques. Furthermore, this effort provided information that could be used in the development of guidance for monitoring programs. Both radon and radon-daughters showed strong variations associated with low wind velocities and stable atmospheric conditions as well as diurnal variations associated with thermal inversions. Average radon concentrations also showed seasonal dependence with the highest concentrations occurring during fall and winter. Comparison of radon concentrations and working levels among three stations showed strong dependence on wind direction and velocity. Radon concentrations and working-level distributions for each month and each station were analyzed. The average maximum, minimum, and modal (peak of a frequency - distribution) concentrations and working levels were estimated with observed frequencies. Working-level variations paralleled radon variations but lagged by less than one hour. The highest working levels were observed at night when conditions of higher secular radioactive equilibrium for radon-daughters exist.

Continuous measurements of radon concentration in air and the working level at a height of 1 m were made utilizing the continuous radon monitor.[8] The report of these studies gives an overview of the techniques that were developed for measuring radon and its daughters in air. Particular note was given to those factors affecting accuracy and precision, with specific emphasis on measurements in occupational and environmental situations. Based on this experience with continuous monitors, including those manufactured by the Eberline Instrument Corporation, the staff believes that these systems provide a reliable and comprehensive data base for research and routine ambient monitoring applications.

During the period of the study, Anaconda's milling-operation conditions were changed several times. Among these changes were the covering of two small inactive tailings piles with local soil; expansion and reconstruction of the tailings dam; addition of evaporation ponds; and alteration of the tailings discharge in an attempt to increase moisture in the beach areas. The amount of stockpiled ore was increased several times. These alterations affected the rate of radon release and confounded assessment of the influence of climatic and seasonal parameters on ambient radon concentration.

As expected, radon concentration and WL showed a significant decrease in concentration with increasing distance from the mill. Radon concentrations were about 10,000 pCi/m^3 directly over the tailings (in agreement with previous Argonne National Laboratory studies using a different technique[9]) decreasing to about background levels at 10 km from the mill. The concentration of radon-222 in air at 0.5 km was between 600 pCi/m^3 and 3600 pCi/m^3 depending on direction. At 1 km from the tailings, the radon concentration is about 300 pCi/m^3, 700 pCi/m^3, and 2500 pCi/m^3 to the southwest, south, and east, respectively. This increased concentration in the east was due to prevailing winds and to adjacent sources of radon, wind-blown tailings, and local topography. Extrapolation of the radon concentration to long distances from the mill, specifically to the south and southwest, suggests a background concentration of between 200 and 300 pCi/m^3.

The range of the averages of background concentrations of radon in air at a station 25 km from the millsite (measured from December 1977 to December 1978) was 183 to 505 pCi/m^3. The lowest average observed was during May, the highest during October. The fall showed the highest average radon concentration (408 pCi/m^3), and spring showed the lowest (190 pCi/m^3). The average background outdoor WL was reported as 1.5×10^{-3} during late morning and early afternoon for areas remote from the Anaconda Uranium Mill and the Homestake Partners Mill.

At this station, the frequency of observation of the modal radon concentration during the winter of 1978 was 25.1%, whereas it was 15.8% at a second sampling station. Comparison of the modal concentrations for each month and season revealed distinct site characteristics, not only with respect to background concentrations, but also in dispersion patterns. The combined concentrations at the two stations may represent a better radon background value for the Anaconda Mill than could be obtained by local sampling.

The seasonal-average radon concentrations were lower during the spring and summer. This may indicate that conditions pertaining to atmospheric dispersion, such as higher mean wind velocity and vertical mixing, are then more prevalent.

2. YELLOWCAKE DRYING AND PACKAGING

2.1 Radioactive Emissions

An important composite source of radioactive emission from the mill occurs at the end of the ore processing line--the yellowcake drying and packaging operation. In view of the relative shortage of documented technical data about releases from the yellowcake stacks, the EPA's Office of Radiation Programs-Las Vegas Facility (ORP-LV) has concentrated on measuring this source.

A series of tests on yellowcake drying and packaging stacks was conducted at six mills from April 1977 to August 1978.[10] Five of these mills employ the acid-leach process; United Nuclear-Homestake Partners (UNHP) uses an alkaline-leach process. A general description of each mill and the yellowcake exhaust air cleanup system(s) in use at the time the tests were made are included in the study report.[10] The isokinetic sampling technique used for all stack tests was the modified EPA method 5 as defined in "Standards of Performance for New Stationary Sources."[11]

Six yellowcake grab samples, not associated with stack tests, were collected at four different mills and the amount of uranium daughter radionuclides contained was determined. Coincidentally, the samples were also used to provide a cross-check of the analytical capabilities of three different laboratories. There was generally good agreement among the laboratories (EPA, Eberline Instrument Company and LFE Corporation Environmental Analysis Laboratory) in the analytical results obtained for concentrations of radionuclides in the yellowcake samples (U-238, U-234, and U-235 and the daughter nuclides thorium-230, radium-226, lead-210, and polonium-210). In the majority of comparable cases, results are within the 2σ counting error range.

The sampling and analytical results presented in tabular form in Reference 10 include individual stack test results and calculated uranium emission rates; emission rates for radionuclides other than uranium (i.e., thorium-230, radium-226, polonium-210, and lead-210); ratios of daughter radionuclides to U-238 parent for stack test samples; U_3O_8 drying, packaging, and emission rate parameters; variability of measured yellowcake emission rates; and daughter radionuclides in yellowcake as percent of U-238 parent; results of inter-laboratory cross-check results for uranium; and radionuclide concentrations in grab samples of yellowcake.

The study showed that United Nuclear Church Rock (UNC) released an average of 0.1% of the U_3O_8 dried and packaged, Sohio released an average of 0.006% of the U_3O_8 dried and packaged, and Union Carbide released an average of 0.09% of the U_3O_8 dried and packaged. The Union Carbide result is identical to the release rate calculated by Argonne National Laboratory in their studies of the radioisotopic composition of yellowcake.[12]

The Sears study showed that measured emission rates from a yellowcake processing stack can routinely vary by a factor of from two to five when tests are conducted without any controls on the mill operating parameters. The EPA tests also show that major anomalies (e.g., a ruptured filter in the exhaust clean-up system) can cause variations of as much as a factor of 20 in the measured emission rate. It appears that the major operational parameter that affects the emission rate is simply whether yellowcake is or is not being dried or packaged during the testing period. An emission rate measurement representing only one operating condition could bias estimates of the annual average source term considerably.

2.2 Particle Size Distribution of Yellowcake Emissions

A study of particle size distribution of yellowcake emissions from drying and packaging stacks at uranium mills was conducted by the Office of Radiation Programs-Las Vegas Facility (ORP-LV) of the EPA.[13] Samples were collected from the dryer and packaging stacks at the United Nuclear Corporation Uranium Mill near Churchrock, NM, using an Andersen[14] eight-stage vertical impactor fitted with an after-filter in combination with equipment as specified in EPA Method 5 as defined in "Standards of Performance for New Stationary Sources."[15] This device collects particles in a manner compatible with determining the mass distributions as a function of aerodynamic diameter. Based on their studies, the authors concluded that the yellowcake particle emissions from the uranium mill packaging and dryer stacks can be characterized by mass median aerodynamic diameters of 1.62 and 1.19 μm. If respirable particulate matter is defined as particles with aerodynamic sizes ≤ 2.5 μm, then the packaging stack yields a respirable fraction of 69%, while that of the dryer is 90%.

2.3 Solubility of Particulate Effluents

A basis for calculating the radiation dose to a given organ following inhalation of a radioactive aerosol is provided by the "Task Group Lung Model" (TGLM) as described in the report of the Task Group on Lung Dynamics for Committee 2 of the ICRP.[17] This model describes the retention of inhaled particulates in the lung and their subsequent redistribution to other body tissues according to particle size and chemical composition. Currently recommended values of retention half-times and regional distribution fractions for these three classes are given in

ICRP Publication 19.[18] Because of the relative paucity of data upon which to develop a more sophisticated model, chemical compounds have been classified simply as class Y (those that are retained in the lung for years), class W (retained for weeks), or class D (for days).[19]

The methodology used herein for estimating radiological impacts of uranium milling incorporates the TGLM classification of the long-lived radionuclides of interest.[17] Following the TGLM recommendations, uranium and thorium were previously placed in class Y, while radium, lead, and polonium were considered to be class W. Because the chemical and physical forms of these elements in ore, tailings dust, and yellowcake were uncertain, these classifications were not considered to be highly reliable. Moreover, since the dose to a particular organ predicted to result from a given inhalation exposure can change by a large factor depending on the pulmonary clearance parameters (i.e., solubility classification), two solubility studies were undertaken in order to provide a firmer basis for applying the TGLM to the calculation of radiation doses from airborne mill effluents.

Both programs had as their objective the determination of maximum dissolution rates under conditions that approximated the physiological environment within the pulmonary lung. The first study was completed by the Inhalation Toxicology Research Laboratory (ITRL) of the Lovelace Institute.[20] Only yellowcake from the production lines of four different mills was examined. The dissolution rate was measured in a blood serum simulant and in 0.1 M HCl. For all samples and soluent, there appeared to be an easily dissolved fraction and a relatively insoluble component. The former was identified with the ammonium diuranate [$(NH_4)_2 U_2O_7$)] content of the yellowcake and the latter with the uranium octoxide (U_3O_8).

ITRL's measurements were subsequently confirmed by Battelle Pacific Northwest Laboratory (PNL)[19] which used yellowcake samples from the same four mills. Dissolution in simulated lung fluid was measured in vitro by a batch technique that gave the highest rate among several methods that were tried. Samples of uranium diuranate and octoxide were also studied. As a result, U_3O_8 was given a Y classification in accord with the earlier recommendations of Steckel and West[21] and of Cooke and Holt.[22] The diuranate proved to have a dissolution half-time of less than a day, placing it in Class D, whereas the material studied by Cooke and Holt had been assigned to class W. Since yellowcake usually contains significant, but variable, fractions of diuranate and octoxide, the finding of fast- and slow-dissolving components was not surprising. The ITRL and PNL data are in relatively good agreement although the more insoluble fraction of 3 of the 4 samples was assigned to class W by PNL and class Y by ITRL. In retrospect, the PNL experimental technique would be expected to yield shorter half-times than the method of ITRL.

On the basis of these data, PNL recommended that yellowcake be assigned a mixed classification of 60% D - 40% W. If one considers the results of both studies relative to the yellowcake drying process in use at the four mills, it appears that the thermal history of the product is very important. These data suggest that product from mills using steam dryers (maximum temperatures in the range of 120 - 180°C) should be classified as more soluble than yellowcake that has been processed through a high temperature roaster (600 - 800°C), with a larger proportion converted to octoxide.

2.4 Yellowcake Composition

The uranium content of yellowcake is conventionally expressed as octoxide although the output of some mills actually contains little uranium in this form. Other long-lived nuclides also are carried through the process, but to a much smaller extent than uranium, and are present in the yellowcake. In order to make a complete assessment of the radiological impact of yellowcake releases to the atmosphere during drying and packaging it is necessary to know the concentration of these other radioactive species. Several recent studies supported by the NRC have provided additional information about the composition of yellowcake.

Merritt[23] reviewed much of the information available in reports from the early 1960s and stated that the uranium product from acid-leach circuits generally contained less than 0.1% of the radium and less than 5% of the thorium that were present in the ore. Thorium was reported to be virtually insoluble in alkaline-leach circuits while radium dissolved to the extent of 1.5-3% and was mostly carried through into the yellowcake.

References 24 and 25 reported a significant range in the carryover of Th and Ra depending on the purification process being employed. The concentration of thorium was given as 0.9% (ion exchange) to 5.3% (alkyl phosphoric extraction) of the ore content, and 0.02% to 0.22% for the radium. Sears, et al,[2] pointed out that solvent extraction with amine rather than alkyl phosphoric acid may reduce to less than 5% the amount of thorium in the yellowcake. For their cost/benefit analysis, the ORNL group conservatively chose values at the upper end of the ranges, namely a Th-230 content of 5% and a Ra-226 content of 0.2% of the U-238 activity in the yellowcake produced by the acid-leach processes. These values were used in most, if not all, subsequent assessments of the impacts from specific mills.

Recent measurements of yellowcake composition were made by groups from Argonne National Laboratory, the EPA Office of Radiation Programs (Las Vegas, NV) and Battelle Pacific Northwest Laboratory. For the studies at Argonne,[12] composite monthly yellowcake samples (from 2 to 13 per mill) were obtained from four different mills in New Mexico, Colorado, and Wyoming (all used a sulfuric acid leach). The range in average Th-230 activity as a percent of the U-238 activity among the mills was 0.08-0.46%. For Ra-226, with allowance for two apparently anomalous values out of 13 samples from one mill, the range was from the detection limit up to 0.01%. The Pb-210 values for the two mills from which data were available were 0.01% and 0.03%.

The EPA Office of Radiation Programs in Las Vegas also measured yellowcake composition in samples from five mills, two of which were included in the ANL study.[10] The results on samples from acid-leach circuits (4 of the 5 mills) were consistent with the ANL findings. The range in average concentrations from these four mills, expressed as percent of the U-238 activity, were as follows: Th-230, 0.10-0.70%; Ra-226, 0.0003-0.028%; Pb-210, 0.005-0.086%. The samples from the one alkaline-leach circuit included in this survey showed much higher concentrations of 2.3% for Th-230 and 0.5% for Ra-226. The result for thorium stands, in contrast to earlier reports in the literature; essentially no Th reached the end product of alkaline processes.

As part of his solubility studies, Kalkwarf[19] also determined the composition of yellowcake in individual samples from four mills, three of which used acid leaching. His results are similar in magnitude to the values quoted above, namely 0.086-0.88% for Th-230 and 0.009-0.048% for Ra-226. The sample from the one alkaline-leach mill confirmed the presence of Th-230 at a concentration of about 3% and Ra-226 at about 1% of the U-238 activity. No values for Pb-210 were reported.

3. TAILINGS

3.1 Particulates

Battelle Pacific Northwest Laboratory studied the nature and behavior of uranium-mill tailings particles acted upon by wind stresses.[26] Field measurements were made at three uranium mills in the Ambrosia Lake District of New Mexico, many of them at an alkaline carbonate-leach plant. Two other tailings piles investigated were at plants employing the acid-leach process. The investigation consisted of field and modeling studies designed to develop data and relationships between particle suspension, wind speed, and other important variables. Four major tasks comprised the study.

3.1.1 Tailings Particle Characterization

Surface and core samples (to a depth of 40 cm) were taken from selected areas of the tailings piles; the concentrations of U-235, U-238, Pb-210, Ra-226, and Th-230 were determined as a function of depth, and considerable variation was noted. For the alkaline-leach plant generally, daughter radionuclides of uranium were in radioactive equilibrium. Acid-leach tailings showed some depletions of Th-230 due to solubility in the acidic slurry, which was confirmed by considerably higher levels in water samples. Particle size distributions and associated radioactivity concentrations showed much higher specific activity in the 7-20 μm fraction than for larger particles, but all size fractions contained significant radioactivity. A complete spectrum of elements taken through x-ray fluorescence showed uranium, selenium, and molybdenum well above ambient levels.

3.1.2 Tailings Particles in the Vicinity of the Plant

Soil samples taken from the surface (out to about 8 km from the tailings) and, in some cases, from below showed the presence of tailings particles. Isopleths showed a general pattern similar to the pattern for prevailing winds. Radium-226 and lead-210 levels ranged from a few hundred disintegrations per minute (dpm) per gram near the pile to background levels of a few dpm per gram at distances several kilometers from the pile. Estimates of radon release from contaminated soil indicated that the dispersed radium contributed significant amounts of radon to the air. Association of radionuclides with particle size fractions was determined through particle size separations. The concentration of radioactivity in the soil showed that mixing in the upper several centimeters had produced a roughly exponential decrease in activity with depth. At distances of several kilometers from the pile, surface and subsurface concentrations reached ambient levels. The effect of floodplain areas on soil-particle reclassification was apparent in one transect north of the tailings pile sampled.

3.1.3 Characterization of Airborne Particles and Measurement of Fluxes

Many field experiments were carried out at the alkaline-leach plant to characterize airborne particle transport from the tailings pile as a function of wind speed, height and direction. The sampling array provided samples from above the pile and at various downwind points when wind was blowing within a given sector and at different speeds. The expected general trend of very low upwind concentrations, increasing concentrations across the pile, and subsequent return to background levels at distances of a few kilometers was found. Concentration changes as a function of wind speed and height up to 15 m showed no consistent pattern, demonstrating the very complex nature of the suspension process. The distributions of radionuclides on airborne particles confirmed that the specific activity of the smaller size fraction was greater than for larger particles. Fluxes of particles could only be roughly bracketed as a function of wind speed because of wind variations between samples taken from crosswind points in the vicinity of the tailings pile and further downwind. Apparent anomalous concentration variations with height from the ground could not be reconciled with knowledge of wind character near the ground. Downwind concentrations were referenced to guidance levels in 10 CFR 20 with the conclusion that Th-230 likely represents the radionuclide of most concern. Elemental composition of airborne particles was reasonably consistent with that reported for the tailings material with selenium being present in considerably greater abundance than in local virgin soil. The great complexity of the system studied emphasized the considerable uncertainties in applying calculational models to suspension, deposition, and transport.

3.1.4 Model Development

A transport and deposition model was developed and applied to the alkaline-leach tailings pile. Actual site meteorology was organized into joint frequency distributions of wind speed, direction, and stability for a seventeen-month period. The model utilized deposition velocities of each particle size; thus calculations of net vertical fluxes to the ground as well as air concentrations at ground level were possible. The model was applied using an actual size distribution of composited airborne particle samples from the alkaline-leach tailings pile. Resulting fluxes to the ground at various distances were in reasonable agreement with relative surface concentrations actually measured. The model has not yet been exercised using experimentally derived source-windspeed data. Additional work is recommended to compare the predictions of this and other models with the data available and to determine the sensitivity of the output (downwind airborne concentrations and deposition) to the source-term description.

3.1.5 Conclusions

The results of Battelle's extensive studies and overall conclusions as related to each specific task can be summarized as follows:

1) Tailings particle characterization

   a) The alkaline carbonate-leach tailings, water-dispersed particulates from the top 0.5 cm of the pile were characterized by about 40% of the Pb-210, U-238, Th-230, and Ra-226 being associated with particles ∿ 7 μm (∿11 μm aerodynamic effective diameter) and smaller in diameter. The mass of particles in this size range was about 9%. Particles collected directly from the slurry discharge point, then size-fractionated in the liquid, were shown to have about 12% of the active material associated with the ≤ 7 μm range; these particles accounted for only about 2.5% of the mass.

   b) Concentrations of Ra-226, Th-230, and Pb-210 were of the order of 400 to 900 dpm/g (∿ 2-4 × 10^{-4} μCi/g) for the bulk surface alkaline-leach tailings particles. The presence of approximately equal concentrations of these daughter products of uranium showed them to be in equilibrium. Uranium-238 was ∿10% or less of the daughter products present. Core samples showed variation in radium activity per gram with depth but practically all results were within a factor of two of the average.

   c) Surface samples of acid-leaching tailings selected to represent the very fine material were found to be about 10 times more radioactive per gram than the coarse material samples.

   d) Selenium was found in the tailings at a level of about 200 ppm, or about 100 times that in ambient soil. Molybdenum and uranium were also found in concentrations higher than in background soil.

2) Tailings particles in the vicinity of the plant

   Particles containing uranium and daughter radionuclides are readily detected in soil samples within several kilometers from both alkaline-leach and acid-leach tailings piles. At one alkaline-leach plant it was estimated that dispersed Ra-226 in soil will emit about 30% as much radon as is currently emitted from the tailings pile itself.

Surface layers of soil (1 to 2 cm deep) contain much higher concentrations of radium than deeper layers of soil. At distances beyond about 6.4 km, the decrease with depth is much less, but at these distances background concentrations are being approached. Soil particles classified by a wet sieving and sedimentation methods showed the radioactive material to be associated with all particle-size fractions, with a large fraction associated with soil particles less than 125 μm in diameter. A clearly bimodal distribution of fractions of Pb-210 associated with particle-size increments was observed with one mode centering on about 7 to 20 μm and the other mode centering on about 100 to 150 μm.

Soil modification by river flood action was manifest in floodplain regions. These regions showed unusually large fractions of particles in the 7- to 20-μm range.

The results clearly showed the long-term deposition of tailings particles in the vicinity of the uranium mills. In principle, these concentrations in soil could be reconciled with transport and deposition models.

3) Characterization of airborne particles and measurement of fluxes

The data on airborne solids concentrations in g/m^3 and airborne mass fluxes in g/(m^2-day) show that tailings material is eroded by wind and removed from the pile. Erosion occurs both from the tailings pile sides as well as the flat top surface. Concentrations and fluxes decrease with distance north of the pile and tend to be within the same order of magnitude as backgound at 4000 m from the pile.

4) Model development

The development of a transport and deposition model provided a framework for prediction of ground and air concentrations from a source of airborne particles. The model, when applied to particles whose size distribution was measured at the downwind rim of the tailings pile, gave relative ground deposition patterns similar to those found in the field study. Clear-cut definition of size and radionuclide composition of particles leaving the pile as a function of wind speed is needed to constructively exercise the model under many conditions. Although field studies have been made to obtain the necessary detailed source-term information, an application of the model using these field data has not been made to date. Furthermore, the field data on airborne particles has not disclosed consistent relationships among the source term and other parameters.[26]

3.2 Radon

Any assessment of the radiological impact of radon from a uranium mill tailings pile requires knowledge of its rate of release and the influence of various physical and meteorological parameters. A variety of approaches has been used to evaluate the quantity of radon released to the atmosphere, both from specific sites and from typical soil; most involve collection and subsequent analysis of radon or radon-daughters at or above the soil surface.

The objectives of the Battelle Pacific Northwest Laboratory studies were to develop and apply an absolute method for determining radon emissions from uranium tailings.[27] Utilizing in situ gamma-ray spectrometry techniques, Ra-226 and Rn-222 (actually Pb-214) concentration gradients were measured as a function of depth in tailings. This was accomplished by lowering a calibrated intrinsic germanium detector to discrete levels within a sealed and cased test-well hole and accumulating a gamma-ray spectrum with a multichannel analyzer. Differences between the vertical distributions of radium and radon were used to calculate a radon diffusion coefficient, the fraction of emanating radon and the flux of radon across the tailings-air interface. A diffusion model was developed that accounted for the nonuniform radium concentrations that occur with depth in tailings piles.

From extensive field measurements at tailings piles the following averaged radon emanation power (α) and diffusion coefficients (cm^2/sec) were determined for areas of differing moisture content and composition.

	Alkaline Leach		Acid Leach	
	α	cm^2/sec	α	cm^2/sec
Wet beach	0.36	0.0010	0.20	0.0027
Dry beach	0.43	0.0040	0.19	0.0037
Berm	0.40	0.015	0.12	0.017

Higher rates of diffusion occurred at the berms, which are comprised of the coarsest tailings material and are the driest portions of the tailings piles. Diffusion rates successively decreased in dry and wet beach areas. Roughly 40% of the radon produced in the more finely ground alkaline-leach tailings was free to diffuse, compared to 20% in the acid-leach material.

Rates of radon exhalation, as determined by the developed diffusion model, were verified by mass balance of the total radium and radon existing in the tailings column. Averaged radon fluxes of 80, 260, 320 atoms/cm^2·sec were determined for wet beach, dry beach, and berm areas of the alkaline-leach tailings, and 60, 190, and 180 atoms/cm^2·sec for comparable areas of acid-leach tailings. These fluxes result in a calculated areal emission rate of radon of about 7 Ci/day per km^2 for both of the acid- and alkaline-leach tailings piles employed in this study.

Radon fluxes determined concomitantly by charcoal-canister adsorption averaged 30% higher than those determined by the diffusion model. Variations of a factor of 2 in the measured radon flux were observed for identically exposed canisters. Increasing exposure periods of a canister generally resulted in reduced estimates of the radon flux.

Measurements were conducted at vegetated and barren sites in close proximity on an abandoned tailings pile. Radon flux from the vegetated site was nearly double that found at the non-vegetated location.

One important objective of this study was to evaluate the influence of meteorological parameters on exhalation of radon from the uranium tailings piles. The researchers concluded that changes of barometric pressure and periods of high local winds did not significantly alter the flux of radon across the tailings-air interface. It appears that short-term variations do not greatly influence the overall exhalation of radon from the uranium tailings piles studies. These results are in contrast to the studies of Clements and Wilkening,[28] who found that atmospheric pressure changes of a few percent occurring over half-day periods resulted in changes of as great as 60% in the radon flux from alluvial soil. Kramer, et al[29] also reported an inverse correlation between radon flux and barometric pressure changes, and described the observed changes as a piston effect involving pressure-induced vertical displacement of the soil gas. The same group also found evidence of depletion of radon concentration of soil gas to depths of 1 m, and reported a somewhat higher radon flux during periods of high wind. Similar effects were observed in the studies of the Argonne group in the measurements of radon and radon-daughters in air in the vicinity of an operating uranium mill.[7]

3.2.1 Radon Attenuation - Laboratory Studies

Ford, Bacon and Davis Utah, Inc. (FBDU) performed experiments to define the effects on radon gas exhalation of various cover materials.[30] These experiments led to results that are predicted by theoretical models. Because mechanical properties of the soils may affect their performance, the following studies were performed to characterize and to quantify the flux-retarding capabilities of different soils and clays, and to correlate the results with the mechanical properties of the respective cover materials.

1) Determine the effective radon diffusion coefficient for each of eight different soils and clays that are representative of the Wyoming and New Mexico mining regions; determine for each the radium content and other soil mechanical properties that are necessary to characterize the radon source in the cover material; determine the radon concentration profile and flux as a function of the cover material thickness; perform measurements on the combination of materials proposed for the Bear Creek project to determine their effectiveness in reducing the radon flux.[31]

2) Perform laboratory measurements to determine the effect of moisture upon the diffusion coefficient of two clays. This was performed by measuring the radon flux and determining the effective radon diffusion coefficient.

3) Determine the emanating power of at least ten different uranium-mill tailings samples. These were to typify tailings, both sands and slimes, from the major uranium mining regions.

4) Investigate the possible effects of plant root penetration upon radon exhalation from revegetated cover materials which have been placed over uranium mill tailings.

The conclusions of these studies by FBDU were as follows:

1) Diffusion coefficients were determined for eight soils using an exact and an approximate solution of the diffusion equation. The calculated coefficients were found to agree at large cover thicknesses and ranged from approximately 2×10^{-3} to 3×10^{-2} cm^2/s. Diffusion coefficients calculated from flux data were found to differ slightly from the values derived from soil radon concentration measurements, but the variation was within expected limits.

   Radon flux attenuation may be predicted if the cover soil and the tailings can be characterized as to moisture content, porosity, density, radium content, and emanating power.

2) Moisture was found to have a dominant effect on the diffusion coefficients of both the tailings and the cover material. An empirical relationship between the diffusion coefficient and the moisture content of the soil was derived. A change of two orders of

magnitude in the value of the diffusion coefficient was observed as the moisture content changed by 20%. It was determined that knowledge of the moisture content of the soil is critical for predicting the attenuation effects of cover material.

Vegetation growth in the cover material seemed to cause a slight increase in radon exhalation when the roots penetrated to the tailings. Test columns containing tailings covered by soil, and in which plants were growing, exhibited wide variations in measured flux values. This variation appeared to be associated with moisture retention and evaporation.

3) The emanating power varied from 6 to 31% for the tailings that were tested. There was only a rough correlation between soil type and emanating power. No correlation was found between particle size and emanating power.

4) There seemed to be an increase in flux when plant roots penetrated through the cover to the tailings. A minimum of 13% increase in flux was noted for plant-covered test columns when compared with base cover. Moisture had a much larger effect on radon exhalation than any other observed parameter. There seemed to be a more pronounced pumping effect as drying occurred in the test columns in which plants were growing than in those which had no vegetation.

Among the more significant findings of this study was the fact that diffusion coefficients determined from the radon concentration data are generally lower than those determined from flux measurements. This difference results from forcing the solution for radon concentration to meet the boundary condition at the air interface so that the calculated concentration matches the measured concentration. This is the region where Fick's Law may not describe the controlling mechanism for radon concentration. However, the radon concentration in the soil and at the air interface is more difficult to measure than the radon flux. Fluxes are normally measured, since performance objectives are specified in terms of the radon flux.

3.2.2 Radon Attenuation - Field Studies

Argonne National Laboratory made a study of a selected alternative for tailings management to mitigate potential radon releases; the alternative was analyzed and appropriate experimental data were presented.[9] The major part of the field study was conducted (starting in June 1977) at the Anaconda Uranium Mill in Bluewater, NM.

Experimental measurements of radon flux over acid- and carbonate-leached tailings resulted in average specific flux values of ϕ_∞ = 0.64 and ϕ_∞ = 0.30 (pCi Rn-222/m^2·sec)/(pCi Ra-226/g), respectively. The average diffusion coefficient for these tailings were, respectively, 2,4 × 10^{-3} and 5.7 × 10^{-4} cm^2/sec. Tailings covered with native soil of clay-silt-sand mixture to a depth of 225 cm resulted in attenuation of flux with diffusion coefficients of 3.7 × 10^{-3} and 3.6 × 10^{-3} cm^2/sec for the two sites, respectively.

3.3 Size and Activity Distributions of Sand From Uranium Mill Tailings Piles

Particle-size distributions and associated gamma activity of sands from the Anaconda Mill tailings pile in Bluewater, New Mexico were determined in a study conducted by P.F. Guill.[34]

Surface samples were taken at locations around the tailings piles. The areas were selected on the basis of the dryness of the sandy surface; they were not covered by water, nor were they caked with dry mud. A vertical trap (2 ft high) constructed of sheet metal was used to remove particles from the air with a minimum disturbance of the wind profile. A 200-mesh (74 micron) screen was used to reduce the pressure drop resulting from placing the collector in the air stream, and standard sieves were employed for the size analysis. Radioactivity in the collected tailings samples was measured by gamma spectrometry. This activity, as a function of particle size, exhibited a broad minimum of about 100 pCi/g around 500 microns and increased to almost 10^6 pCi/g for particles larger than 850 microns and smaller than 106 microns. This increase in specific activity for particles larger than 500 microns in diameter had not been previously reported. Other investigators found decreasing specific activity with increasing particle size.[35]

The radioactivity is divided disproportionately among the sands, slimes, and other dissolved material pumped to the tailings impoundment area. The dissolved material generally contains less than 1% of the mass and less than 1% of the radioactivity of the tailings. The slimes contain 15% to 60% of the mass by weight of the solids, usually on the average of about 25%. The slimes usually contain most of the radioactivity, approximately 3 to 20 times more than the sands. On the average, the slimes have about 75% of the total activity. Therefore, the generalization that the sands will comprise about 75% of the mass by weight but only 25% of the activity of the tailings can be made. Thus, the slimes are considerably more hazardous than the sand by virtue of their greater specific activity.

The results further indicated that size differences exist between tailings from an alkaline-leach process and an acid-leach process, and that there is an age effect. The alkaline-tailings distribution is more narrow than that of the acid-leach tailings; this is to be expected because of the need for finer grinding of the feed ore for the alkaling process.

4. FOOD-CHAIN CONTAMINATION

A pilot study to assess and predict the potential radiological impact of food ingestion pathways for airborne effluents released from uranium milling operations, focusing primarily on ingestion exposures associated with grazing animals and locally raised food crops or garden produce, was undertaken by Argonne National Laboratory in 1979.[36] The study was designed to determine the levels of the long-lived nuclides in the uranium decay series--uranium, thorium-230, radium-226, and lead-210--that might enter the human food chain from milling operations. The levels of human intake of these radionuclides from the food chain, water, and atmosphere were compared to those in control areas distant from mines and mills.

Rabbits, cattle, vegetables, and grass were collected on or near two uranium mill sites. For controls, similar samples were obtained from areas 20 km or more from the mining and mill operations. For the onsite rabbits, the mean Ra-226 concentrations in muscle, lung, and kidney of 5.5, 14, and 15 pCi/kg wet, respectively, were substantially higher than those in the tissues of control animals (0.4, 1.5, and 0.2 pCi/kg). The levels in liver did not differ significantly between the groups. The concentrations in bone (femur and vertebra) were about 9000 and 350 pCi/kg ash for the onsite and offsite animals, respectively. The levels of Pb-210 and Po-210 did not differ significantly for a given tissue between the two groups, except that the Po-210 level in the kidney was greater in the onsite group.

For cattle the results were less complete, but the data indicated that the concentrations in muscle, liver, and kidney do not differ greatly between those grazed near the pile and the controls. The levels of Ra-226, and possibly of Pb-210, appeared to be greater in the femur of the animals near the piles. Vegetables from a residential area on a mill site contained substantially greater concentrations of Ra-226 and Pb-210 than those reported for standard New York City diets.

Grass and cattle dung from land irrigated by water containing 60 pCi/L Ra-226 from uranium mines had concentrations of Ra-226 and Pb-210 that were about 50 and 8 times (respectively) greater than those in control samples.

It is estimated that doubling the normal concentrations in meat and vegetables of uranium and daughter products could increase the dose equivalent rates to the skeletons of persons consuming these foods by 30 mrem/yr or more.

Overall, the results showed that some contamination of the human food chain is likely. The degree of contamination is less than the above results might suggest because the sampling was from locations where maximum contamination levels were expected and was not intended to yield representative or average values. In considering the actual exposure to the residents in the area near the study site, one has to consider certain factors. The region under study had a small population and limited agriculture. Only a small fraction of the homes (<5%) had gardens, and these probably supplied only a fraction of the yearly food for the families involved. It appears that with an admixture of foods from outside the region, contamination of the diet would probably be small. Use of cattle that grazed near the mill as a food source would affect only a few families and, even in such cases, some of the meat consumed would probably come from distant sites.

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APPENDIX H. IMPACTS OF ALKALINE-LEACH MILL

The process of alkaline (carbonate) leaching is described in detail in Appendix B. Briefly, the ore (ground more finely than for acid leaching) is extracted with a mixed sodium carbonate-sodium bicarbonate solution. Heat and pressure may be used and air is usually used for oxidation of the uranium. The solids and liquids are separated in counter-current filters or decantation tanks, and after washing the solids are discarded. The leach liquid is treated with sodium hydroxide to precipitate uranium oxide which then is washed, filtered and dried for packaging.

In some cases, second stage precipitation is employed to reduce sodium concentration and to allow increased recycling of water. Sulfuric acid is used to redissolve the uranium, which is then precipitated with ammonia or peroxide.

The barren leach solution is recarbonated and recycled in the extraction process. After being washed, the solid tailings are slurried in a water stream (separate from other waste waters) and sent to the tailings pond. The extraction solution is continually reused. The volume of liquid wastes from the alkaline mill ranges from 0.3 to 0.8 ton per ton of ore,[1] compared to the model mill value of 1.0 ton with 0.3 ton being recycled.

The waste solution from the alkaline mill will have a pH of about 10 and total dissolved solids of 12000 mg/L compared with pH2 and 35000 mg/L in the acid mill.[1] Most of the difference is in a lower sulfate level in the alkaline waste. Toxic anionic salts of selenium, vanadium and arsenic will be much more soluble in the alkaline solution and might cause serious groundwater contamination problems if the ores contain high concentrations of these elements. In general, most pollutants will move more slowly or be less soluble in alkaline wastes than in acidic wastes. The uranium concentration in acid and alkaline solutions is about the same. Radium concentration in alkaline solutions is from 4% to 20% of that in acid, and the thorium concentration is essentially negligible in alkaline solution.[1]

The yellowcake from the alkaline process contains about 1.8% of the radium originally in the ore, compared with a content about 0.1% in yellowcake from acid leaching. As a consequence more care must be used in ventilation and dust control in handling alkaline yellowcake.

An alkaline mill is not properly an alternative to an acid mill; it is built when necessitated by the properties of the uranium ore to be processed. The cost of alkaline mills is difficult to estimate since none have been built lately; however, it is estimated that capital and operating costs would both be about 15% to 20% greater than for an average acid-leach mill.[2] The costs of pollution tailings control for the alkaline mill would be generally similar,[1] but would differ in a few respects from those of the model mill. Since the yellowcake produced in an alkaline mill is more radioactive, a more expensive dust control device would be required to attain an equivalent effluent radioactivity level.

Since the amount of wastewater, and usually the pollutant level of the alkaline water, is lower than in the acid mill, somewhat less stringent control might be possible. If, however, the anionic wastes (e.g., selenium) were present, a higher control level would be necessary. A smaller surface area would be required for evaporation, and hence smaller but deeper tailings areas could be used. The costs would depend on the height of the dam and could be greater for the smaller area.[1] The costs of liners or covers are not changed other than through changes in area. The chemical compositon of the tailings solution could determine the need for a given liner and the associated cost.

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APPENDIX I. IMPACTS OF A LARGE-CAPACITY MILL

1. INTRODUCTION

The impacts of a large uranium mill [7200 MT, (8000 ST) per day] and associated tailings disposal area(s) are considered and compared to those of four smaller mills [1800 MT (2000 ST) per day] sited in the same general location.

The potential advantages of a larger mill include confinement of the environmental impacts that would be associated with the operation of four smaller milling facilities and their tailings disposal systems to a much smaller area. Capital, operating, and maintenance costs for a larger production center and tailings disposal operation should be less than the aggregate of those for a number of scattered mills. With sources of potential problems localized, the expenses and efforts involved in instituting the necessary control measures (Secs. 8.2 and 8.3) also should be reduced.

A disadvantage inherent in this option is the difficulty of finding an adequate mill location and a tailings disposal area of suitable size and with the necessary characteristics for the containment of a large volume of mill wastes. There would also be a concomitant increase in the cost of transporting ores from a number of distant mines to a common processing facility, as well as the attendant adverse impacts resulting from an increase in vehicular traffic. Moreover, the centralized mill might incur operational problems resulting from wide variations in physical and chemical characteristics of ores coming from different mines (e.g., wide differences in moisture content, grindability, uranium and lime contents), a situation not usually encountered at a mill with an ore feed originating from one mine or a few mines in the same general area and having a fairly uniform and predictable quality.

Siting of uranium mills and associated facilities is influenced by land acquisition problems and by proximity to mines and to suitable tailings disposal sites (App. B), as well as by the characteristics and distribution of ore bodies.

Since the total quantities of discharges for a given output of uranium concentrate will be essentially equal, regardless of the size or number of mills involved, options which facilitate transport of ore to the mill and of tailings from the mill, or which permit more effective control of environmental impacts, are discussed below. Costs affected by mill capacity are included.

2. ENVIRONMENTAL EFFECTS

If tailings disposal is excluded and if the processes and equipment used in the 7200-MT/day (8000 ST) mill are similar to those used in the smaller mills (except for number or size), the environmental impacts of the processes and equipment of the larger mill would be similar to those described in Chapter 6 for the model mill, but greater in proportion to the increased throughput of the larger mill. Because of the larger mill's size and throughput, air-cleaning systems and water usage could be more efficient and the overall environmental impacts (per ton processed) could be less than for four smaller mills. The proportional land area of the mill alone would be reduced only slightly.

The radiological impact from the tailings to receptors at varying distances from the larger mill will be increased by about a factor of four. However, the close-in receptors will experience an increase of less than four times because the effluent component from the large tailings pond, an area source, need not increase proportionately. If the depth of the tailings disposal pit is constrained by geology or hydrology to the same depth as for the model mill, then the effluent component would be the same for one large mill or four smaller ones. If, however, the depth of the pit is unconstrained, the ratio of surface exposed to quantity of tailings contained can be decreased. This could reduce surface emanation of radioactivity considerably. The radiological impact (in terms of man-rem) of a large disposal area to a receptor on its perimeter would be less than that for receptors on the perimeter of four smaller disposal areas. Doses at the fence, trailer, and ranch will be about four times greater than for the 1800 MT/day mill during operation. After mill shutdown, without reclamation, the tailings will dry out and become sources of dust, which would constitute a radiological problem for years. If reclamation is effected, the radiological impact to the region will be negligible if the overburden covering the tailings is not eroded.

The difficulties in siting a large mill and tailings pond, cited above, make it likely that the mill and the pond will be more widely separated than is the case for smaller operations. The slurry pipeline thus would be longer and leaks would be correspondingly more likely; nevertheless, the slurry pipeline would not be a major factor in the siting of the tailings disposal area.[1] Detrimental impacts would be very minor since the system is usually enclosed. If the pipeline were longer than a few hundred meters, a special right-of-way and a system for detecting and controlling any leaks would be required.

3. COSTS

In Table I-1, capital and operating costs are shown for 1800 MT/day and /200 MT/day mills. The costs shown are maximal and are for mills built in areas such as Wyoming where a large industrial base does not already exist. None of the costs include mining or ore transport costs and are estimates developed for the comparison required. Neither do the costs include $1 per ton for a typical (1976) tailings disposal system. Also not included in the cost estimate is the potential for the mill to generate its own sulfuric acid, which might reduce costs as much as 30%. Since the cost of this reagent is 30 to 40% of operating costs (per ton of ore) for a small mill and 50% for the large one, the increase in quantity required for the large mill might make the internal generation of acid more attractive for the large mill than for the small ones. Economics of scale for cost of water have been included in the cost estimates of Table I-1. As can be seen from the cost estimates given in the table, the potential for economies due to increasing mill capacity is unmistakable.

Table I.1. Comparison of Costs for 1800-MT/Day and 7200-MT/Day Mills[a]

Cost Component	Cost (1977 dollars) 1800-MT/Day Mill	Cost (1977 dollars) 7200-MT/Day Mill
Capital Cost		
Total	26,500,000	80,200,000
Per year per MT ore processed[b]	3.13	2.37
Annual Operating Cost		
Total	6,100,000	16,600,000
Per MT ore processed	10.85	7.39
Total Cost		
Per year per MT ore processed	13.98	9.76
Per year per kg U_3O_8[b]	9.30	6.50

[a] From "An Evaluation of Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in the Western United States," prepared by Dames & Moore for Argonne National Laboratory, July 1977.

[b] At 85% mill capacity and 0.15% U_3O_8 in ore.

The tailings disposal cost for the large mill would be very similar to the combined disposal costs for four small mills. The scale of four is not really large enough to change the costs markedly and would only affect excavation costs. If the pit were deep, and the mill more than a mile from the pit, costs might actually increase slightly.

The staff is aware that the costs presented in this appendix are now out of date. It is the staff's opinion that the relationships of the costs are essentially unchanged so that the economies of scale are correctly reflected. An approximate updating of the costs may be obtained by multiplying all cost figures by 1.25 to allow for inflation since 1977.

Reference

1. "Evaluation of Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in Western United States, by Dames and Moore for Argonne National Laboratory, July 1977.

APPENDIX J. EPA INTERIM CLEANUP STANDARDS FOR INACTIVE URANIUM PROCESSING SITES

In accordance with provisions of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA, PL 95-604), the U.S. Environmental Protection Agency (EPA) has published interim criteria for cleanup of open lands and structures at inactive uranium processing sites (as designated under Title I of the UMTRCA). These interim criteria were published in the Federal Register on April 22, 1980, and are reproduced below in full.

Although these criteria are effective only on an interim basis, and only for inactive sites, the NRC staff considers them to be the most carefully reasoned and generally applicable standards now available for land cleanup and decommissioning of uranium mill sites. Therefore, the NRC staff has temporarily adopted these criteria as representing NRC staff positions with respect to land cleanup and decommissioning of uranium mill sites.

If at some later time the EPA modifies these criteria, or proposes or adopts different criteria more directly applicable for active uranium milling operations (as required by the UMTRCA), the NRC staff intends to modify its staff position accordingly. However, on an interim basis, the criteria set forth below are those which the NRC staff would endorse and use as needed in individual licensing proceedings.

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 192

[FRL 1469-8]

Interim Cleanup Standards for Inactive Uranium Processing Sites

AGENCY: Environmental Protection Agency.

ACTION: Interim standards.

SUMMARY: The Environmental Protection Agency (EPA) is issuing interim standards for cleanup of open lands and buildings contaminated with residual radioactive materials (mainly tailings) from inactive uranium processing sites. These standards are also being published simultaneously as proposed standards upon which public comment is being solicited. (See Proposed Cleanup Standards in the Proposed Rules section of the Federal Register.)

EPA has developed these standards pursuant to Section 275(a) of the Atomic Energy Act, as added by Section 206(a) of Pub. L. 95-604, the Uranium Mill Tailings Radiation Control Act of 1978. Pub. L. 95-604 requires the Department of Energy (DOE) to conduct remedial actions for designated inactive uranium processing sites in accordance with standards promulgated by EPA. Buildings and land contaminated with tailings pose a continuing threat to public health. Some of these buildings have been found to have radiation levels which are highly dangerous to anyone exposed to them for long times. Pub. L. 95-604 precludes undertaking remedial action before EPA has promulgated standards. Therefore, we have decided to promulgate interim standards for cleanup of these open lands and buildings, to permit DOE to take remedial actions under Pub. L. 95-604 to alleviate these problems.

DATES: Effective date: April 22, 1980. Comment date: Comments should be received on or before June 23, 1980.

ADDRESS: Comments should be submitted to Docket No. A-79-25, which is located in the Environmental Protection Agency, Central Docket Section, Room 2903B, 401 M Street, SW., Washington, D.C. 20460. The Draft Environmental Impact Statement may be examined at the Central Docket Section. Shortly, after we propose disposal standards for inactive processing sites, single copies of the Draft Environmental Impact Statement may be obtained by writing to the address given below.

FOR FURTHER INFORMATION CONTACT: Dr. Stanley Lichtman, Criteria and Standards Division (ANR-460), Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C. 20460; telephone number 703-557-8927.

SUPPLEMENTARY INFORMATION: Pursuant to Section 275(a) of the Atomic Energy Act, as added by Section 206(a) of Pub. L. 95-604, the Uranium Mill Tailings Radiation Control Act of 1978, EPA has developed standards for the cleanup of open lands and buildings contaminated with uranium mill tailings from inactive processing sites. Pub. L. 95-604 requires the Department of Energy to conduct remedial actions for designated inactive uranium processing sites in accordance with standards promulgated by EPA. (Section 108(a)(1), 42 U.S.C. Section 7915(a)(1)). However, Pub. L. 95-604 precludes undertaking remedial actions before such standards are promulgated.

Lands and buildings contaminated with uranium mill tailings pose risks to public health. The greatest hazard from tailings on open lands is increased levels of radon decay products in buildings. When radon decay products are inhaled, they increase the chance of lung cancer. Exposure to direct gamma radiation and contamination of drinking water and food may also occur.

Tailings usually only pose significant risk to people who are exposed for a long time. However, some homes and other buildings have been found in which the radon decay product concentration is quite dangerous. There are such buildings, for example, in Salt Lake City, and in Canonsburg, Pennsylvania. Several buildings in Salt Lake City are immediately adjacent to a tailings pile, or have tailings in, under, or around them. In some of these, indoor radon decay product concentrations exceed the average occupational concentration limit for uranium miners (0.3 WL).[1] Included among these is a fire station in Salt Lake City, where substantially elevated levels have been measured even when mechanical ventilation is used. In Canonsburg, an industrial park is now located on an inactive processing site. Eight buildings leased to commercial tenants are located directly over heavily contaminated land. Measurements during working hours show that all buildings have substantially elevated indoor radon decay product concentrations, with the highest average daytime level being 0.4 WL. These levels are dangerous and will continue. To allow DOE to begin remedial action under Pub. L. 95-604 to alleviate these hazards, we have decided to promulgate these immediately effective interim cleanup standards.

Studies of indoor background radioactivity in Grand Junction (Colorado), New York State, and New Jersey show that at least 10 percent of houses with basements exceed the interim standard's remedial action level of 0.015 WL. Because of this, we believe it would often be impossible to try to reduce levels for houses affected by tailings significantly below 0.015 WL by removing the tailings. Thus, it is unlikely that the final standards will be set at a level significantly more stringent than the interim action level of 0.015 WL, and remedial actions performed under the interim standard will not have to be redone. Furthermore, although we have not formally solicited public comments on the interim standards, the Nuclear Regulatory Commission and the Department of Energy have been consulted. For these reasons, we believe issuing immediately effective interim cleanup standards is justified.

A statement of the research, analysis, and other available information in support of this interim standard is contained in the preamble to the proposed standards published elsewhere in the Federal Register today. Additional background material may be found in the Draft Environmental Impact Statement being made available in Docket No. A-79-25, which is located at the address given above, and in other information contained in that docket. We invite written comments on these interim standards, and they remain subject to modification in response to such comments and to views expressed orally at public hearings (see below).

In addition to the procedures we followed prior to promulgating these interim cleanup standards, we are conducting the required public review process for promulgating final standards. In the Proposed Rules section of today's Federal Register, we are proposing for comment the cleanup standards for inactive uranium processing sites. They are identical to the interim cleanup standards which are being made effective immediately. Furthermore, EPA intends to hold public hearings on these proposed cleanup standards and on proposed standards for the disposal of tailings from inactive sites. The disposal standards will be proposed for public comment soon, and the Draft Environmental Impact Statement for both proposed standards will be made generally available at that

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[1] A working level (WL) is any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha rays with a total energy of 130 billion electron volts. The working level expresses a concentration of radioactivity in the air, not how much radiation a person receives.

time. Therefore, before these proposed cleanup and disposal standards become final, members of the public will have the opportunity to comment in writing, and to present data, views, and arguments at a public hearing.

Note.—The costs and benefits of these standards are discussed in the Draft Environmental Impact Statement. However, neither our issuance of interim cleanup standards nor the remainder of our program to set remedial action standards for Pub. L. 95–604 require preparation of an economic analysis under Executive Order 12044. We expect the costs of the remedial action program in any calendar year to be less than the $100 million criterion EPA has established (44 FR 30988–30998, May 29, 1979) for requiring an economic analysis.

Dated: April 14, 1980.

Douglas M. Costle,
Administrator.

Part 192 is added to Title 40 of the Code of Federal Regulations as follows:

PART 192—ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

Subpart A—[Reserved]

Subpart B—Environmental Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials From Inactive Uranium Processing Sites

Sec.
192.10 Applicability.
192.11 Definitions.
192.12 Standards.
192.13 Effective date.

Subpart C—Exceptions

192.20 Criteria for exceptions.
192.21 Remedial actions for exceptional circumstances.
Table A [Reserved]
Table B.

Authority: Sec. 275, Atomic Energy Act of 1954, (42 U.S.C. 2022), as amended by the Uranium Mill Tailings Radiation Control Act of 1978, Pub. L. 95–604.

Subpart A—[Reserved]

Subpart B—Environmental Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials From Inactive Uranium Processing Sites

§ 192.10 Applicability.

This subpart applies to open lands and buildings which are part of any processing site designated by the Secretary of Energy under Pub. L. 95–604, Section 102. Section 101 of Pub. L. 95–604, states 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 such 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.

Any ownership or control of an area by a Federal agency which is acquired pursuant to a cooperative agreement under this title shall not be treated as ownership or control by such agency for purposes of paragraph (a)(1) of this section. A license for the production of any uranium product from residual radioactive materials shall not be treated as a license for production from ores within the meaning of paragraph (a)(2) of this section if such production is in accordance with section 108(b).

§ 192.11 Definitions.

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Uranium Mill Tailings Radiation Control Act of 1978.

(b) *Remedial action* means any action performed under Section 108 of the Uranium Mill Tailings Radiation Control Act of 1978.

(c) *Open land* means any surface or subsurface land which is not a disposal site and is not covered by a building.

(d) *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.

(e) *Dose equivalent* means absorbed dose multiplied by appropriate factors to account for differences in biological effectiveness due to the type and energy of the radiation and other factors. The unit of dose equivalent is the "rem."

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

§ 192.12 Standards.

Remedial actions shall be conducted so as to provide reasonable assurance that—

(a) The average concentration of radium-226 attributable to residual radioactive material from any designated processing site in any 5 cm thickness of soils or other materials on open land within 1 foot of the surface, or in any 15 cm thickness below 1 foot, shall not exceed 5 pCi/gm.

(b) The levels of radioactivity in any occupied or occupiable building shall not exceed either of the values specified in Table B because of residual radioactive materials from any designated processing site.

(c) The cumulative lifetime radiation dose equivalent to any organ of the body of a maximally exposed individual resulting from the presence of residual radioactive materials or byproduct materials shall not exceed the maximum dose equivalent which could occur from radium-226 and its decay products under paragraphs (a) and (b) of this section.

§ 192.13 Effective date.

The standards of this subpart shall be effective April 22, 1980.

Subpart C—Exceptions

§ 192.20 Criteria for exceptions.

Exceptions to the standards may be justifiable under any of the following circumstances:

(a) Public health or safety would be unavoidably endangered in attempting to meet one or more of the requirements of Subpart A or Subpart B of this part.

(b) The goal of environmental protection would be better served by not satisfying cleanup requirements for open land, § 192.12(a) or the corresponding part of § 192.12(c). To justify an exception to these requirements there should be a clearly unfavorable imbalance between the environmental harm and the environmental and health benefits which would result from implementing the standard. The likelihood and extent of current and future human presence at the site may be considered in evaluating these benefits.

(c) The estimated costs of remedial actions to comply with the cleanup requirements for buildings, § 192.12(b) or the corresponding part of § 192.12(c), are unreasonably high relative to the benefits. Factors which may be considered in this judgment include the period of occupancy, the radiation levels in the most frequently occupied areas, and the residual useful lifetime of the building. This criterion can only be used when the values in Table B are only slightly exceeded.

(d) There is no known remedial action to meet one or more of the requirements of Subpart A or Subpart B of this part. Destruction and condemnation of buildings are not considered remedial actions for this purpose.

§ 192.21 Remedial actions for exceptional circumstances.

Section 108 of Pub. L. 95-604 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 which pays part of the cost, and in consultation, as appropriate, with affected Indian tribes and the Secretary of the Interior. Under exceptional circumstances satisfying one or more of the conditions 192.20 (a), (b), (c), and (d), the Department of Energy may select and perform remedial actions, according to the procedures of Sec. 108, which come as close to meeting the standard to which the exception applies as is reasonable under the exceptional circumstances. In doing so, the Department of Energy shall inform any private owners and occupants of affected properties and request their comments on the selected remedial actions. The Department of Energy shall provide any such comments to the parties involved in implementing Sec. 108 of Pub. L. 95-604. The Department of Energy shall also inform the Environmental Protection Agency of remedial actions for exceptional circumstances under Subpart C of this rule.

Table A.—[*Reserved*]

Table B

Average annual indoor radon decay product concentration—including background (WL)	0.015
Indoor gamma radiation—above background (milliroentgen per hour	0.02

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APPENDIX K. DETAILED COSTS OF MITIGATING ALTERNATIVES

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APPENDIX K-1. COSTS OF ALTERNATIVES FOR CONTROLLING AIRBORNE WASTES

During operations, uranium milling will produce a number of airborne contaminants. In this appendix the costs of alternative methods for control of dust from ore storage, ore handling and crushing, yellowcake drying and packaging, and the tailings pond are considered. The methods are described in more detail in Chapter 8.

1. ALTERNATIVES TO CONTROL DUST FROM ORE STORAGE

1.1 Water Spray

One-half hectare would be used for ore storage, and for this alternative it is assumed that the storage pad would be sprinkled daily with about 3 mm of water. It is assumed that a sprinkler system similar to that used for general irrigation is set up. The capital costs can be scaled from the costs of larger systems using the scaling factor "$X^{0.6}$." Based upon the costs of a 70-ha system in 1973, the 1980 costs of an ½-ha system would be about $9,000. Maintenance and operation would be 10% per year, or $900. The cost of water is taken as $0.13/m^3$,[1] and since 4,500 m^3/year would be used, the cost would be $600. Therefore, the total annual cost of the system would be $2,100 and the total lifetime (15-year) cost (capital and annual) would be $32,000.

1.2 Windbreak

For this alternative, a 3.7-m high sheet metal or wooden fence would be erected on three sides of the ½-ha ore storage pad, each side being 80 m long. The cost is linearly scaled and escalated from Reference 2 for a total cost of $17,000 for either type of fence.

1.3 Ore Warehouse

The cost of an ½-ha warehouse is estimated to be $3.6 million ($720/m^2). A ventilation and scrubber system would be required, and costs for the system would probably be a substantial multiple of those cited below for the various dust control alternatives.

2. ALTERNATIVES TO CONTROL DUST FROM ORE HANDLING, CRUSHING, AND GRINDING OPERATIONS

Ore is crushed to reduce the large raw lumps to diameters of the order of 2.8 cm or less. This process can be carried out on relatively dry ores, and a substantial source term (Sec. 5.3.2) from dust and radon can arise. Similarly, the handling and movement of the crushed ores can generate dust and radon releases. Grinding of ores refers to the reduction of ore particle size from 2.5 cm to about 28-mesh size in a rod or ball mill. This process is generally carried out wet at from 50% to 70% solids. These processes are described in more detail in Appendix B.

This two-step process (crushing and grinding) can be replaced by a single-step process, wet semi-autogenous grinding, which results in an equivalent product. A brief description of this process is given in Section 8.2.

The incremental capital costs for dry operations are estimated as $95,000 and operating costs at about $0.12/MT ore (1% increase).[3] In addition to basic equipment costs, a dust collection system would be required for the dry crushing unit.

Costs are given below for dust collection equipment (described in Sec. 8.3.1) for handling, storage, and crushing facilities. The costs, summarized in Table K-1.1, are for ores containing about 6% water in an 1800 MT/day mill.

2.1 Orifice Dust Collector

Separate dual collector units for the ore bin and for the combined crusher and screen units are used in the base case. The crusher and screen unit has a capacity of 27,000 cfm and the bin unit 2700 cfm. Similar capacities are assumed for the other alternatives. Capital costs for the crushing unit collector would be $90,000 and for the bin dust collector $23,000. Annual operating costs, including power, water, maintenance, and labor, would be $14,000. Lifetime costs would be $323,000.

2.2 Wet Impingement

The dust units for the bin and grinder would cost $27,700 and $110,600, respectively. Annual operating costs would be $16,800, and total lifetime cost $390,000.

Table K-1.1. Costs of Combined Ore Bin, Crusher and Handling Dust-Removal Units

Alternative	Efficiency, %	Costs (thousands of 1980 dollars) Capital	Annual	Lifetime
Orifice	94	55	14	325
Wet impingement	97.9	138	16.8	390
Low-energy Venturi	99.5	205	32.8	695
Reverse bag filter	99.9	387	33.2	885
Reverse bag plus HEPA		407	91.3	1775

2.3 Low-Energy Venturi

The units for the bin and grinder would cost $37,500 and $167,500, respectively. Operating costs would be $33,200 per year, and the total lifetime costs would be $700,000.

2.4 Reverse Bag Filter

The units for bin and grinder would cost $77,000 and $310,000, respectively. Operating costs would be $33,200 per year, and the total lifetime costs would be $885,000.

2.5 Reverse Bag Filter Plus HEPA Filter

This alternative would involve adding HEPA filters to the bag filter. A gas dryer consuming about 14,000 m^3 of natural gas per year would be required to prevent moisture condensation and freezing of the filters during winter. The capital costs (including bag filter) would be $410,000, annual operating costs $91,000, and lifetime costs $1,775,000.

3. ALTERNATIVES TO CONTROL DUST FROM YELLOWCAKE DRYING AND PACKAGING

Two basic types of alternatives exist for reducing the radioactive dust usually generated by the drying and packaging of yellowcake for shipment. One control method is to use one or combinations of ventilation systems and dust retention units in conjunction with the drying and packaging. Costs and efficiencies of various possible units are given in Table K-1.2.

Table K-1.2. Costs of Yellowcake Dust-Removal Alternatives

Alternative	Efficiency, %	Costs (thousands of 1980 dollars) Capital	Annual	Lifetime
Wet impingement	97.9	45.0	5.5	130
Low-energy Venturi	99.5	55.5	10.8	220
Medium-energy Venturi	99.7	66.1	15.9	305
High-energy Venturi	99.9	71.5	23.8	430
High-energy Venturi plus HEPA filter		108.2	29.4	550

The costs have been figured for 1700 m^3/minute units. The other method of dust reduction is to forego the drying step and ship the crude yellowcake to the refining mill as a wet slurry or cake. If this is done, drying and packaging of yellowcake is unnecessary. Dust will no longer be generated, and the yellowcake source term becomes negligible. The yellowcake refining mill does, however, currently charge a premium of about $1.50/kg of U_3O_8 (about 2% of the U_3O_8 price) for processing the slurry.[4] The excess cost would be balanced to a large extent by the reduction in equipment and operating costs for drying and for environmental controls.

The cost of installed drying and packaging equipment (including piping, instrumentation, etc.) is estimated at $1.3 million, or about 15% of the total mill equipment cost of $8.6 million.[1] Prorating the mill's operating cost ($12/MT of tailings), the cost reduction is $1.80/MT, or about $1.10/kg yellowcake. The capital cost saving is about $0.02/kg yellowcake. The maximum lifetime dust removal cost is $128,000 ($71,000 capital), equal to $0.06/MT tailings and $0.04/kg yellowcake. On this basis, the net cost to the mill operator of shipping yellowcake as a slurry is $0.32/kg, about $290,000 annually and $4.4 million lifetime.

A variation of the above procedure is the shipment of yellowcake as a "wet cake"; i.e., the slurry would be partially dried by filtering or centrifuging, and the resulting moist form shipped to the conversion plant. An advantage of this option is that the wet cake could be shipped in standard drums, whereas shipment of slurry would require a larger, thick-walled container. The savings of equipment and operating costs would be those listed above, except that a centrifuge, or equivalent apparatus, would still be required for preliminary drying. The cost of the dewatering apparatus could be recovered from lower shipping costs.

4. ALTERNATIVES TO CONTROL DUST AND RADON FROM THE TAILINGS PILE

Dust from dry tailings can be minimized by keeping as large an area as possible under water, by sprinkling with water, or by various chemical sprays. Radon emissions can be minimized primarily by maintaining a layer of liquid water over the tailings, and to a lesser extent by keeping the tailings saturated with water. Chemical sprays which cover the surface will have variable effectiveness in controlling radon exhalation; inasmuch as they are applied as an interim dust control measure during active use of the pile, such chemicals are expected to have little, if any, effect on the emission of radon.

The costs of keeping the tailings under water are affected by seepage, evaporation, and recycling rates and by any unusual distribution of tailings or strengthening of the embankment. The costs of keeping the tailings under water would be a complex function of these variables, dependent on mill operating conditions, and difficult to evaluate.

The costs of sprinkling the dry beaches of the tailings pile would be largely the costs of operating a water-sprinkling truck. About 1 ha per day would be sprinkled with about 0.3 cm of water in eight hours. Water could be taken from the tailings pond with negligible cost.

To estimate the cost of the sprinkling operation, the following factors were considered. An 18-MT ore truck traveling 360 km per day and having a useful life of five years is quoted as having total annual operating costs (including driver) of $66,000.[1] The sprinkler truck is assumed to travel about 50 km per day and have a useful life of 15 years. The costs are taken as one-third of those for the ore truck for all items except the driver, who is assessed at full cost. The estimated sprinkling cost is $35,000 per year and $525,000 lifetime.

Chemical spraying is intended to stabilize surfaces against dust and erosion. Various synthetic and natural polymers have been used for the purpose. The treatment usually must be repeated every one to two years. Costs cited for treatment range from $4200 to $5800/ha, with a value of $4800 being assumed here.

References

1. Dames and Moore, "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in the Western United States," Dames and Moore report prepared for Argonne National Laboratory, July 1977.

2. M. B. Sears, et al., "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluent in the Nuclear Fuel Cycle for Use in Establishing 'As Low as Practical' Guides--Milling of Uranium Ores," Oak Ridge National Laboratory, ORNL-TM-4903, May 1975.

3. M. S. Peters and K. D. Timmerhaus, "Plant Design and Economics for Chemical Engineers," 2nd edition, McGraw-Hill, 1968.

4. "Nuclear Fuel," Vol. 3, No. 17, 21 August 1978.

APPENDIX K-2. COSTS OF ALTERNATIVE SPECIAL TAILINGS CONTROL PROCESSES

Costs of a number of special tailings control processes (described in Sec. 8.2) are considered in this appendix. Some of these processes are simple, involving as few as one piece of machinery, while others involve complex networks of machines and pipes. Also, the design and costs depend rather specifically on the exact purpose of the installation. Most of the processes described below are used only in tailings disposal Alternatives 7 and 8. The costs quoted are tailored to that use; however, the values cited should give general ideas of costs for other installations. Process numbers on the flow sheets in Appendix K-4 (Figs. K-4.1, K-4.3, K-4.4, and K-4.5) are keyed to the numbers given in the pertinent discussion in this section. Detailed descriptions and engineering cost evaluations of most of the mechanical processes are contained in Reference 1.

1. SANDS-SLIMES SEPARATION

Sands would be separated from the slimes in two cyclone separators costing (installed, 1980) $66,000.

2. IN SITU DEWATERING

For in situ dewatering of tailings, it is assumed that the tailings pit bottom (about 42 ha area) will be filled above the water table, lined with a clay or plastic liner, and a filter drain system will be installed over the liner. The drain system consists of a network of 6-inch (15 cm), perforated, PVC pipes placed at about 30 m intervals (with a total length of 17,000 m at $7.00/m) on the liner, and gravel fill (at $12/m^3) would be used as filter medium. The thickness of the filter gravel will be about 0.3 m. Sumps, along with drainage pipes and electrical equipment, would be needed to drain any liquids collected by the system during operations. Tailings will be deposited directly into the pit and drained liquids will be pumped to the evaporation pond. Based upon review of cost data on the above items, the installed costs for the system (except liners) is estimated at about $680,000.

3. FOSSIL-FUELED EVAPORATORS

The capital costs of evaporators and associated equipment with an evaporation capacity of 4.6×10^5 m^3 of water per year are estimated as $1.7 million (1980 costs).[1] With a 70% thermal efficiency, 90,000 MT of coal per year would be required, at a cost of $2.9 million.

4. EVAPORATION POND

The evaporation pond is assumed to have an area of 40 ha (no credit is given to direct evaporation from tailings) and to require a 5-m-high dam; the bottom would be lined with hypalon. The costs are estimated as $350,000 for site preparation, $315,000 for the dam, and $3.3 million for the liner. After 15 years of operation, about 30 cm of soluble salts would be deposited on the pond bottom. It is postulated that these solids would be collected and disposed of in the tailings impoundment. The cost to restore the entire 40-ha evaporation pond area is estimated to be $500,000. The total cost is thus $4,470,000. This cost applies to alternatives 3, 7, and 8, where tailings are dewatered. If direct evaporation from tailings is taken into account (the staff has estimated that about one-third of the liquids will evaporate from the tailings area), then the evaporation pond will need to be only two-thirds as large (27 ha), and the cost is estimated as $2,880,000.

5. HORIZONTAL VACUUM BELT FILTER

A horizontal vacuum belt filter, for use as an additional tailings treatment step prior to disposal, probably could be used to filter and wash whole tailings or sands; however, the filtration of slimes alone probably would not be feasible. For the whole tailings from the model mill, it is estimated that a filter of 64 m^2 area,[2] at a cost of $465,000, would be required. For separated sands an 8 m^2 filter costing $140,000 would be used.[2,3]

6. LIME NEUTRALIZATION

The slimes and liquid would be neutralized with lime. Details of the equipment and cost estimates are given in Reference 1. The costs are estimated to be $785,000, including lime-handling and mixing equipment, instrumentation, and auxiliary equipment. Each day 22 MT of lime would be used at a cost of $32.40/MT delivered.[1]

27

35.00

38.00

7.a. SLIMES FILTRATION (disc filter)

The neutralized slime slurry would be treated in thickeners and filtered in vacuum disc filters (200 m^2) at a total cost of $1.35 million (1980, installed).[1]

7.b. SLIMES FILTRATION (bed filter)

For open-air dewatering of tailings (by use of a dewatering filter bed), it is assumed that an area sufficient to hold three years' production of slimes in a one-meter-deep layer (about 80 ha) would be necessary. After one year of dewatering, the tailings would be recovered for processing or disposal and the vacated portion of bed prepared for reuse. Small berms would be needed to enclose the entire area and to form cells to separate fresh from dewatered tailings. Also, grading and drainage would have to be provided. Preparation costs are estimated at \$56,000/ha.[4-7] Restoration costs at the end of operation are also expected to be about \$5,000/ha.

8. CEMENT FIXATION

Costs of equipment for cement fixation are also described in Reference 1. Materials-handling and mixing equipment, instrumentation, and associated apparatus would be required, at an estimated cost of \$1.40 million (1980). To provide a sufficient degree of resistance to leaching by groundwater, a mixture of one part cement to five parts slimes (dry basis) would be required, or 110 MT of cement per day at \$62/MT.

9. ASPHALT FIXATION

Costs of equipment for asphalt fixation are described in Reference 1. The capital costs would include materials-handling and mixing equipment, wiped film evaporators which combine mixing of asphalt with further drying of tailings, instrumentation, and associated equipment, for a total cost of \$5.15 million (1980). About 750 kg of asphalt would be required per metric ton of dry slurry (420 MT/day) at a cost of \$34.50/MT of asphalt. The equivalent of 50 MT of coal per day (cost, about \$1600) would be required for evaporation of water from the asphalt mixture carried out in the wiped film evaporator.

10. BARIUM CHLORIDE TREATMENT

The costs of barium chloride ($BaCl_2$) treatment are largely those of the material plus the costs of a series of lined settling ponds. The amount of $BaCl_2$ added can range from 0.03 to 0.1 g/L of tailings solution,[8] and about 1200 MT of tailings solution (Ch. 5) must be treated. The cost of $BaCl_2$, including transportation, is about \$500/MT (1980) for a materials cost of \$18 to \$49 per day. A total load requirement for 40 ha in three or four plastic-lined settling ponds would cost about \$2.6 million. Restoration would add about \$204,000 more to the costs.

11. ION EXCHANGE

Although not considered in the alternative tailings disposal programs, the removal of radium from tailings solution using ion exchange is a potentially viable process.[9] To remove about 99.5% of the radium from the tailings solution, about 1200 kg/day of barite (natural barium sulfate) would be required as a disposable ion-exchange bed. The cost would be about \$250/day (\$95,000/year). The used barite would be relatively inert and could be disposed of in the tailings pile. Lime neutralization and filtration would be required pretreatment of the tailings solution.

12. NITRIC ACID MILL

The capital and operating costs of a nitric acid mill may be estimated by using the costs given in Reference 10 for a sulfuric acid mill and comparative costs for the two types of mills given in Reference 1. For equipment, the costs are about \$7.1 million for the sulfuric acid mill and \$37.7 million for the nitric acid mill. Additional capital costs include those for building and site development, utilities and connections, engineering costs, and contingencies. These items add \$16.8 million to the costs of the sulfuric acid mill. The non-equipment items for the nitric acid mill probably would not be proportional in cost, since a substantial fraction of the extra equipment costs are for similar items in stainless steel, rather than wood or mild steel; furthermore, a larger plant area would be required for the equipment of the nitric acid plant. It, therefore, is assumed that the non-equipment costs for the nitric acid plant are about double those of the sulfuric acid plant, or about \$35 million.

Operating costs for the sulfuric acid mill (including reagents) are given as \$8.40 to \$9.84 per ton of ore processed and for the model mill are assumed to be \$9.00 per ton.[10] Total operating costs of \$12.50 per ton are then obtained for the nitric acid mill. Annual operating costs for the model mill would be \$5.6 million, if sulfuric acid were used, and \$7.7 million for the nitric acid version. Lifetime (15 years) costs are \$108 million and \$189 million for sulfuric and nitric acid mills, respectively. Tailings disposal costs for the nitric acid mill are discussed in Section 10 of Appendix K-4. The costs of the two types of mills are summarized in Table K-2.1.

Table K-2.1. Costs of Nitric and Sulfuric Acid Mills (in millions of dollars)

	Nitric Mill	Sulfuric Mill
Equipment (including piping and instrumentation)	37.7	7.1
Construction and building	35	16.8
Lifetime (15-year) operating costs	116	84
TOTAL (rounded)	189	108

References

1. M. B. Sears et al., "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluent in the Nuclear Fuel Cycle for Use in Establishing as Low as Practical Guides--Milling of Uranium Ores," Oak Ridge National Laboratory, ORNL-TM-4903, May 1975.
2. Enviro-Clear Co., "Horizontal Belt Vacuum Filters," brochure, undated.
3. R. H. Perry and C. H. Chilton, "Chemical Engineers Handbook," 5th Edition, McGraw-Hill, 1973.
4. Bond Evaluation to State of Wyoming for Lucky Mc Uranium Mill, July 1977.
5. Bond Evaluation to State of Utah for Humeca Uranium Mill, 13 September 1976.
6. W. B. Kays, "Construction of Linings for Reservoirs, Tanks and Pollution Control Facilities," Wiley Interscience, 1977.
7. Letter from R. E. Williams, University of Idaho, to Fred Vaslow, Argonne National Laboratory, March 1978.
8. Letter from P. C. Rekemeyer, Union Carbide Corp., to R. A. Scarano, U.S. Nuclear Regulatory Commission, 1 February 1978.
9. M. S. Peters and K. D. Timmerhaus, "Plant Design and Economics for Chemical Engineers," 2nd edition, McGraw-Hill, 1968.
10. Dames and Moore, "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in the Western United States," Dames and Moore report prepared for Argonne National Laboratory, July 1977.

APPENDIX K-3. COSTS OF ALTERNATIVE TAILINGS POND LINERS

The first step beyond no surface treatment is the removal of topsoil and the compaction of exposed surface with heavy machinery. In estimating costs, the staff has assumed that 0.6 m of topsoil are removed and stockpiled. The costs of removal and subsequent grading and compaction are taken as \$1.65/m^3 removed, or \$0.33/m^2 for 0.2m of topsoil removed.

For most installations of plastic or clay liners, the above treatment will have to be carried out first and these costs added to the liner costs, which for 0.75-mm polyester reinforced hypalon are \$6.90/m^2. Polyvinylchloride (PVC) can also be used in lower strength applications if it is protected from light and to some degree from oxygen. The corresponding total cost for PVC is about \$4.90/m^2. (See Appendix K-4 for a discussion of the various factors that influence these costs. A list of the types of liners is given in Table 8.3 in Chapter 8.)

The costs of clay depend greatly on the local availability of a suitable clay; e.g., a clay having a large proportion of montmorillonite, such as bentonite (see Supplement). Large deposits of bentonite and similar clays occur in Wyoming, South Dakota, Texas, Arizona, and Utah, in the uranium mining regions, and smaller deposits exist in all the Western states. In this discussion it is assumed that clay is available from an onsite borrow pit, and can be excavated, hauled, and emplaced as readily as overburden. Compaction of the clay liner is assumed to be done to meet quality assurance and testing requirements more stringent than those for soils used as cover materials. The borrow pit is assumed to be resurfaced and revegetated. Total cost for installation of a 1-m thick clay liner is taken as \$2.55/m^2 (including \$1.20/m^3 for excavation, \$1.25/m^3 for controlled spreading and compacting, and \$0.10/m^3 for restoration of borrow area). If clay must be transported from other sources, a cost of \$0.27/m^3-km must be added for transportation costs.

The common costs of preparing a base for the liners are included in the area preparation costs; however, the requirements for a foundation for a synthetic liner can be stringent, and in some rare instances, preparation costs may be comparable to liner costs.

APPENDIX K-4. COSTS OF ALTERNATIVE MILL TAILINGS MANAGEMENT PROGRAMS

This section contains a discussion of the monetary costs of each of the tailings management alternatives described in Section 8.4. In evaluation of costs it has sometimes been necessary to add details of the procedures not needed for the brief descriptions in Chapter 8. Many of the individual costs used in this section have been described or evaluated in one of the other portions of this appendix.

The costs of disposal of mill tailings are dependent upon a number of factors, some of which are site-specific. Where costs for certain materials or operations are likely to vary from site to site, the staff considered a range of possible costs and/or evaluated costs of substitute materials. For example, costs of both clay and synthetic liners were evaluated, because costs of clays can vary considerably; in some areas clay might not be available at reasonable cost.

The most highly variable costs appear to be those associated with earthwork, which in most cases represent a large portion of the costs for mill tailings disposal. These costs depend upon the topography of the disposal site and its surroundings; if it is necessary to haul material up steep grades, costs will increase. Another factor affecting costs of earthwork is ease of excavation and the type of excavating equipment used. Materials to be excavated could include a range of rock and soil types having vastly different hardnesses: hard rock, weathered rock, soft rock, consolidated soils, unconsolidated soils, sands, etc. In general, the more difficult the excavation, the more elaborate, and expensive, the equipment and the lengthier the time required. The availability of such materials as clay or sand could affect costs. If the necessary materials are readily available locally, no incremental costs would be incurred; if they must be purchased and/or hauled, costs could increase significantly. A range of costs for earthwork, reflecting the aspects discussed above, is given in Table K-4.1. Where it appears likely that the character of a procedure contained in the tailings management alternative will, in itself, raise or lower this cost, this aspect is recognized and an appropriate adjustment of the cost is made.

Table K-4.1. Unit Costs Used in Evaluations[a]

Factor	Range of Costs	Selected Value
Excavate, Load, Haul ($\leq$ 1 km), Deposit	\$1.05-\$1.30/m^3	\$1.20/m^3
Truck Transport ($\geq$ 1 km)	\$0.25-\$0.30/m^3-km	\$0.27/m^3-km
Spreading and Compacting (Cover & Fill)[b]	\$0.30-\$0.55/m^3	\$0.45/m^3
Spreading and Controlled Compacting (Liner & Dam)[b]	\$1.10-\$1.35/m^3	\$1.25/m^3
Compacting Soil Already in Place	\$2100-\$6500/ha	\$2600/ha
Installation of Clay Liner[b]	\$1.95-\$3.20/m^3	\$2.55/m^3
Installation of Cover Material[b]	\$1.45-\$1.95/m^3	\$1.75/m^3
Installation of Hypalon Liner (30 mil)	\$6.15-\$7.50/m^2	\$6.90/m^2
Installation of PVC Liner (30 mil)	\$4.30-\$5.25/m^2	\$4.90/m^2
Resurfacing and Revegetation	\$4500-\$5500/ha	\$5000/ha

[a] Only those costs common to many alternatives are listed. For specialized costs, see the appropriate alternative.

[b] Installation of liner or dam material, and, hence, the degree of compaction, must meet more stringent quality assurance and testing requirements than cover or fill materials.

The costs of excavating, hauling, and depositing earth fill are estimated as \$1.20/m^3. If resurfacing and revegetation of the excavated areas are necessary, this will add a cost of \$0.10 per cubic meter of earth excavated; however, in instances where reclamation is done as a part of mining operations, this cost is not included. Costs for spreading and compaction are estimated as \$0.45/m^3, assuming no special quality assurance or testing requirements are necessary. If stringent quality control or testing requirements are applied, such as for liners or dam construction, the spreading and compaction costs may be as high as \$1.25/m^3. The staff has estimated costs for installation of a one-meter-thick cover at \$1.75/m^2, and installation of a one-meter thick liner at \$2.55/m^2. These costs of clay or earth for installation as liner or cover material are based upon the assumption that they can be obtained from an onsite borrow pit close, to the tailings disposal area and, hence, no transportation costs have been included. Transportation (> 1 km) of clay or other soil can add $0.27 per kilometer for each cubic meter of material moved.

The staff has estimated unit costs for other operations as follows. Compaction of soil in place (such as preparation of pit bottoms) is estimated to cost $2600/ha, although costs can vary widely depending on the equipment used. For installation of plastic liners, the staff has estimated costs of $6.90/m^2 and $4.90/m^2 installed for a 30-mil thick liner of hypalon and PVC, respectively. Chemical stabilization over tailings during operation (e.g., Alternative 6) is assumed to be done once per year for five years, at a total cost of $4800/ha.

The unit costs quoted above have been given in 1980 dollars. Total costs of viable alternatives have increased substantially, on an average of about 50%, from those quoted in the draft (costs were estimated in 1978 dollars) of this document. These increases can be attributed principally to the increase in energy and fuel costs, and the increase in petroleum product prices, which have increased by as much as 100% over the past several years.

Costs for reclamation, or restoration, of the surface of the covered tailings pile vary widely depending on location, topography, and surface treatment.[1-10] The staff considers an average cost of $5000/ha to be reasonable. Similarly, the costs of riprap vary over a great range. If gravel can be used, costs of about $6/m^3 will be incurred.[11] If larger stones or special types of riprap are required, costs could range to $12-30/m^3.[11,12] The staff has assumed a thickness of 18 inches (0.5 m) of riprap at a cost of $12/m^3, equivalent to a cost of $60,000/ha, assuming no hauling is necessary. If hauling is needed, cost of riprap will be higher, as shown in Appendix K-6.

The costs estimated for the various tailings management alternatives also depend on the assignment of the costs. Several alternatives include disposition of tailings in available open pits (from mining); in these cases, the costs of pit excavation and backfilling with overburden are considered to be those of mining and mine reclamation to be incurred regardless of tailings disposal requirements, and are not included in costs of alternatives. The costs incurred because of the tailings management program, e.g., lining of the pit, installation of a cap, are assigned to the alternative. In all cases, the staff has considered carefully the assignment of costs and has attempted to make a reasonable and realistic assignment of all costs attributable to a given tailings management alternative. The costs assigned to the alternatives are summarized in Table K-4.2 and are discussed for each alternative in the following sections.

The staff considers the cost estimates to be adequate for the comparison of alternatives and to support decisions regarding generally applicable regulations. Although it may be shown that unit costs for isolated cases may be greater than those assumed herein, it appears that the estimates of the total costs of the tailings disposal programs are in agreement with similar estimates for programs developed in the recent past for individual licensing actions. Generally speaking, the recent licensing experience indicates that while costs may vary from case to case, the incentive to optimize the efficiency and cost effectiveness of operations has led mill operators to meet interim environmental and safety goals by selecting materials and disposal techniques that best fit the individual situations. Further discussion of the cost bases used by the staff in this assessment is given in Appendix K-8.

1. BASE CASE (Fig. K-4.1)

As described in Chapter 5, an initial basin would be formed by building low earthen embankments on the four sides of a square. Mill tailings would be slurried into the basin and as the basin filled, coarse fractions of the tailings (sands) would be used to raise and broaden the embankments. The embankments would be compacted on the outer side to provide strength. The initial earthen embankment would be 3 m high, 3 m broad at the top, and 15 m broad at the base; each side would be 947 m long at the centerline. The final embankments would be 10 m high, 13 m broad at the crest, and 53 m at the base; the initial centerline length would be unchanged. The volumes of the initial and final embankments would be 102,000 m^3 and 1,250,000 m^3, respectively.

It is assumed that no specific measures would be used to control dust; also, after cessation of operations, no control measures for the tailings, other than fencing off of the area, would be applied. Details and estimated costs of the operations are as follows:

a. The total volume of the starter embankments would be 102,000 m^3. The costs included are excavating, hauling, and depositing 102,000 m^2 at $1.20/m^3, and spreading and compaction costs for the outside half of the embankment, only (51,000 m^3) are estimated at $1.25/m^3. Thus, the total cost would be $190,000.

b. The capital and yearly operating costs of the tailings pumping and distribution system, with the mill adjacent to the tailings pond, are considered to be a part of the mill operating and capital costs, so are not added here or in similar alternatives.

Table K-4.2. Detailed Capital Costs of Alternatives (thousands of 1980 dollars)

			Alternative																	
		1	2						3		4	5		6	7 and 8[a]				9
			Option (1)			Option (2)									Cement		Asphalt		
Operation	Base Case		A	B	C	A	B	C	Belt	In Situ		Clay	Hypalon		Disc	Bed	Disc	Bed	
Preparation of retention basin	900	4,140	1,480	1,480	1,370	2,690	3,730	3,310	3,290	3,290	10,770	10,800	10,030	1,280	-	-	-	-	1,280
Preparation of sidewalls	-	-	3,960	4,000	1,150	2,160	2,130	860	-	-	-	-	-	-	-	-	-	-	-
Liner																			
Clay	-	-	1,330	1,330	1,020	1,350	1,810	1,380	1,070	1,070	-	3,060	-	2,040	-	-	-	-	2,040
Hypalon[b]	-	-	3,590	3,590	2,760	3,660	4,900	3,730	2,060[d]	2,060[c]	-	-	8,250	5,500	-	-	-	-	5,500
Decantation system	-	-	100	100	100	100	100	100	-	-	100	-	-	100	-	-	-	-	100
Evaporation[c]																			
Pond (Hypalon lined)	-	-	2,880	2,880	2,880	2,880	2,880	2,880	4,470	4,470	2,880	2,880	-	2,880	4,470	4,470	4,470	4,470	2,880
Others	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,700[g]	1,700[g]	1,700[g]	1,700[e]	
Chemical stablization	-	-	-	-	-	-	-	-	-	-	-	-	-	380	-	-	-	-	380
Sand washing, drying	-	-	-	-	-	-	-	-	-	-	-	-	-	-	210	210	210	210	-
Lime neutralization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2,270	2,270	2,270	2,270	-
Filtration	-	-	-	-	-	-	-	-	6,380[f]	680	-	-	-	-	1,350	5,040	1,350	5,040	-
Fixation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,400	1,400	5,150	5,150	450
Cover	-	4,200	1,460	1,460	1,030	1,460	1,460	1,260	2,700	2,700	2,400	2,120	2,230	4,200	-	-	-	-	2,100
Reclamation and Stabilization	-	500	-	-	-	-	-	-	-	-	400	590	560	1,620[g]	-	-	-	-	400
Total Cost	900	8,840	-	-	-	-	-	-	-	-	16,550	-	-	-	9,700	13,390	13,450	17,140	-
1. Clay Lined/ with Evap. Pond	-	-	11,210	11,250	7,550	10,640	12,110	9,790	17,910	12,210	-	19,450	-	12,500	-	-	-	-	9,630
2. Hypalon Lined/ No Evap. Pond	-	-	10,490	10,530	6,310	9,970	12,220	9,160	-	-	-	-	21,070	12,980	-	-	-	-	10,110
3. PVC Lined/ with Evap. Pond	-	-	-	-	-	-	-	-	18,900	13,200	-	-	-	-	-	-	-	-	-
4. Others	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,930	10,620	10,680	14,370	-

[a] Costs shown for Alternative 7. For Alternative 8, add $1,880,000 for well drilling to all options.

[b] Where hypalon is used to line the tailings area, no evaporation pond or decantation system is used; liquids in this case are assumed to evaporate directly from the tailings area.

[c] Where evaporation ponds are used for alternatives 3, 7, and 8, evaporation is assumed to be from evaporation ponds only, due to dewatering, and would require 40 ha. For other alternatives, evaporation from tailings basin will result in less area required for the evaporation pond; 27 ha is used.

[d] Values indicated are for PVC liners.

[e] Costs shown for fossil fuel evaporator.

[f] Includes hauling of dewatered tailings to pit.

[g] Includes recontouring of surface of and rock cover over outer slope (10 horizontal to 1 vertical) of dam.

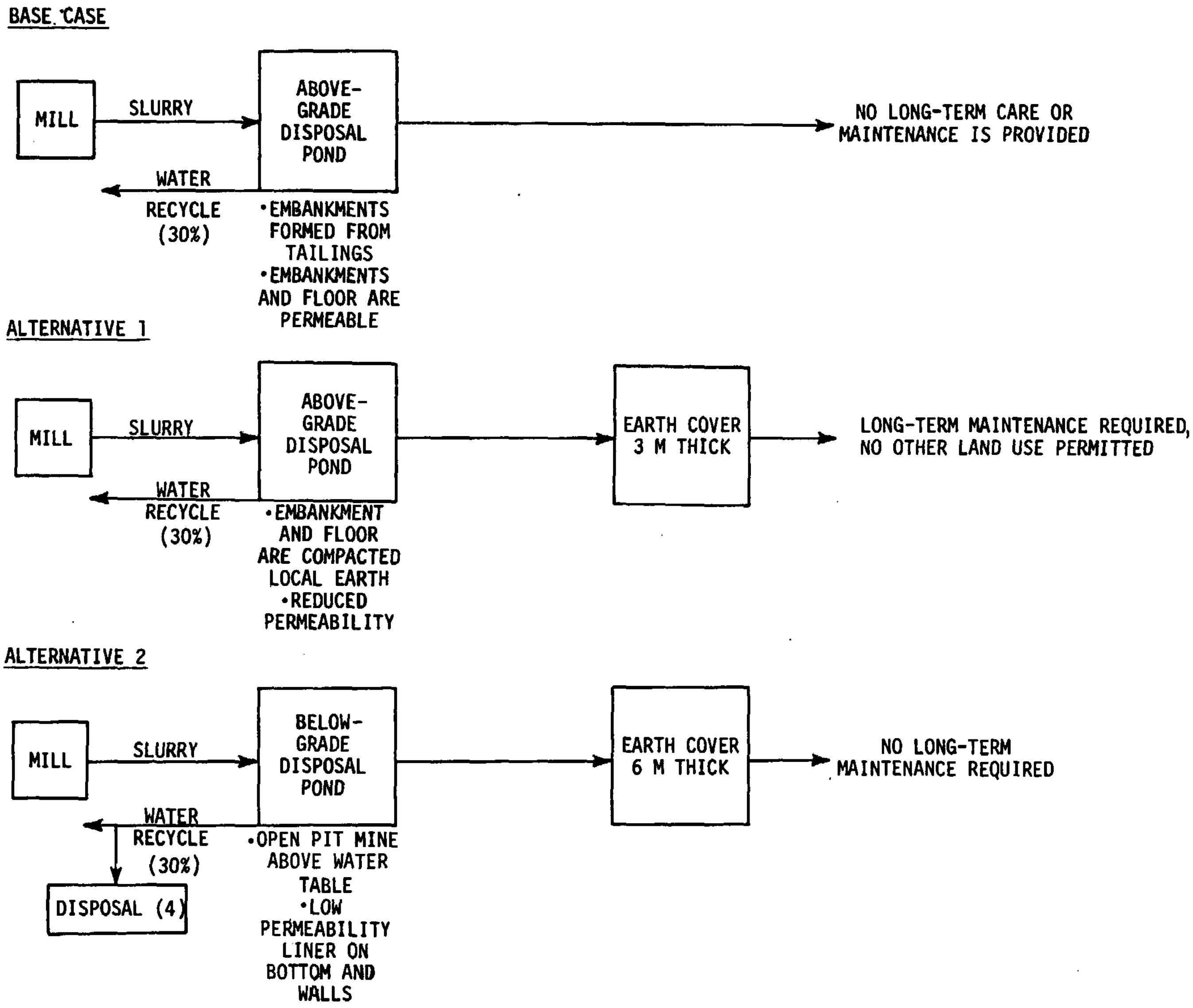

Fig. K-4.1. Tailings Treatment Flow Sheet for Base Case and Alternatives 1 and 2.

c. Although tailings pumping costs are not considered, the incremental costs of compacting the tailings on the outside of the embankment are. About 41,000 m^3 per year would have to be compacted at an estimated unit cost of $1.25/$m^3$, for a total cost of $51,000 per year. Over the 14-year period, operating costs would amount to $710,000, so that lifetime costs for this alternative would be $900,000 (1980 dollars).

d. The fencing around the tailings pond is considered to be an original part of the mill costs and not charged here. The costs of these actions are listed in Table 11.8.

2. ALTERNATIVE 1 (Fig. K-4.1)

Under Alternative 1, the embankment for the tailings pond would have the same shape and dimensions as the final structure of the base case. However, the construction would be essentially finished at the start of mill operations, and the structure materials would be compacted local soils entirely rather than tailings. Before construction of the dam, 0.6 m of topsoil would be removed from the entire pond area (100 ha) and the exposed surface would be compacted. Diversion ditches and drains also would have to be constructed. After operations had begun and dry beaches of tailings began to form, water sprinkling could be used for dust control, if the tailings surface were strong enough to hold sprinkler trucks. After operations had ceased and the tailings were sufficiently dried to support heavy equipment (two to five years after additions had ceased), the surface would be covered with 3 m of acceptable fill material. After sealing, the entire area would be covered with topsoil and revegetated.

The estimated costs of these operations and some further details are discussed below:

1. The costs of removing the surface soil would depend on the character of the soil (hardness, rocks exposed, etc.), the contours, and the distance the soil must be moved, as in the base case. For reasons cited thereunder, a cost of $1.20/$m^3$ for excavation and $2600/ha for compacting the exposed surface is assumed, for a total cost of $980,000 (600,000 m^3). The volume of the tailings dam would be 1,244,000 m^3, and the cost of deposition and compacting of the soil $2.45/$m^3$, for a total of $3.05 million. Construction of diversion ditches and drains will cost $110,000.

2. The sealing with 3 m of earth fill would occur three years after operations ceased. Use of the designated unit results in estimated costs, for 80 ha covered, of $4.2 million.

3. Reported costs for restoration and revegetation have varied widely, depending on such factors as the geographical areas and treatment necessary for the surface.[1-10] An average value of $5000/ha for spreading six inches of topsoil and revegetation seems reasonable and is used here. About 100 ha would be treated for a total cost of $500,000.

3. ALTERNATIVE 2 (Fig. K-4.1)

Alternative 2 includes deposition of untreated tailings in an available surface mine pit, with sides and floor sealed by a low permeability liner. Two options are considered: (1) the lining installed below the water table on the prepared original floor and walls of the pit; (2) the lining installed above the water table on compacted backfill and on the prepared walls of the pit.

In order to present somewhat realistic comparative costs, all computations are based on the conceptual mine pit shown in Figure K-4.2. The average depth of the mine is taken to be 30 m; the top of the water table is at 25 meters. The stepped sides are approximated by a smooth (2 vertical, 1 horizontal) slope. The dimension "L" is variable, dependent upon the method by which the side walls are prepared. The mine is assumed to be backfilled with 8 m of earth fill (to above the water table) and lined with (approximately 1 m) either clay or hypalon, with a cover thickness of about 6 m. The tailings layer will be 15 m thick with an area of 43 ha. Fill material below the liner (Option 2) will be deposited and compacted at a cost of $0.90/$m^3$, and fill above the liner (Option 1) is assumed to be deposited only, at a cost of $0.45/$m^3$; compaction of pit bottom (Option 1) or fill below the liner (Option 2) is done, since the bottom must be prepared before the liner can be installed. The pit bottom and sidewall areas to be lined will thus vary, depending on which option and which method are utilized. Since the cover will be 6 m thick in this alternative, it is assumed that no compaction is necessary, and deposition costs are estimated to be $0.45/$m^3$. In arriving at these unit costs, the staff has estimated that double handling costs due to tailings disposal will result in incremental earth moving costs of 75% over mine excavating costs (i.e., 75% of $1.20/$m^3$), and that 50% of the time, tailings disposal operations will cause second handling of mined material.

Before the liner and tailings could be placed in the mine, the floor and sidewalls would have to be prepared. The floor would be compacted as indicated above, and the slopes of the sidewalls

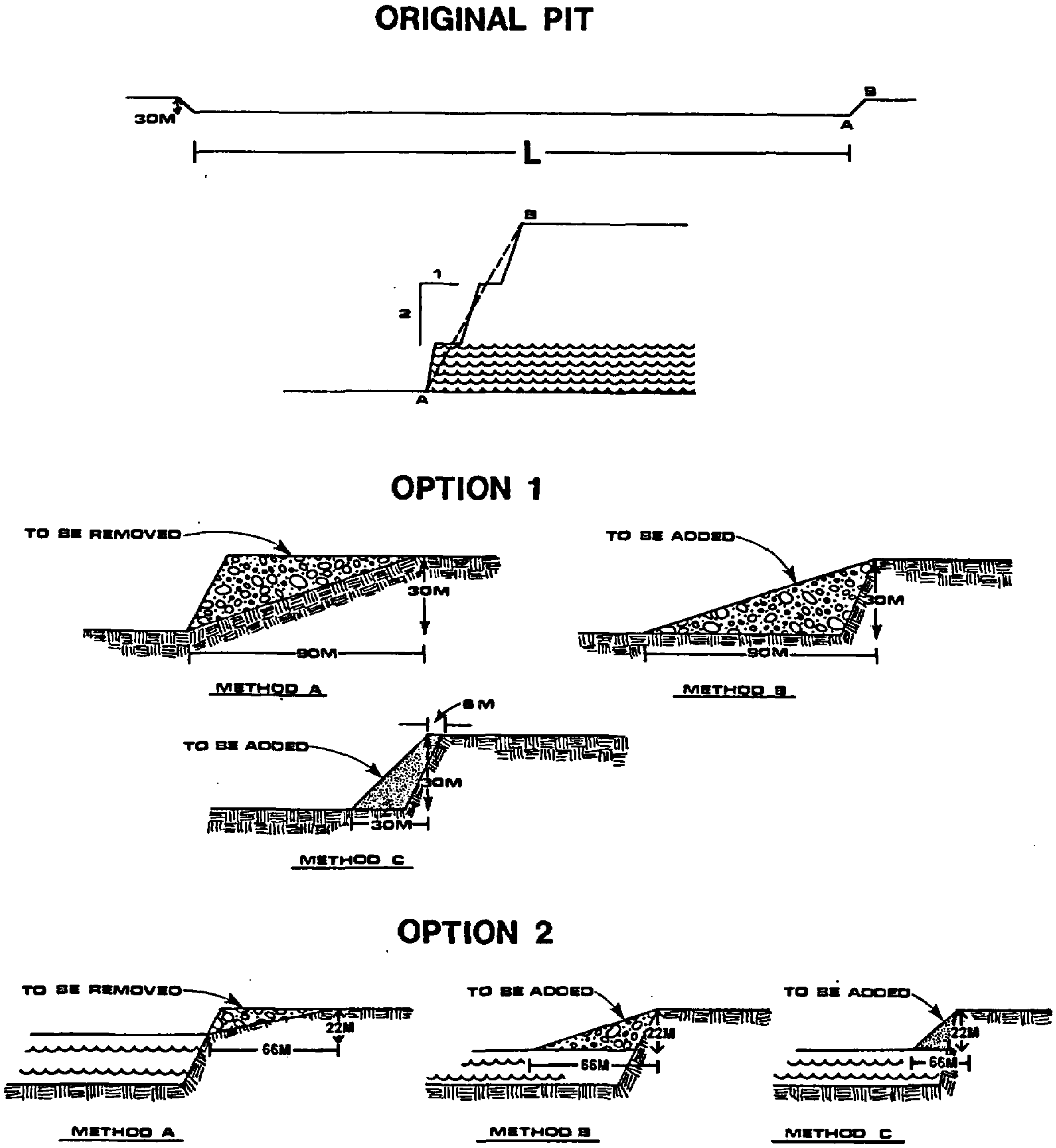

Fig. K-4.2. Schematic Diagram of
Pit Treatment under Alternative 2.

reduced by cut and fill procedures. For the purpose of illustration, calculations have been made for the two extremes; all cut (method A of Fig. K-4.2) and all fill (method B of Fig. K-4.2); in practice, some combination of these would probably be used. In addition, a reduction of slope by the emplacement of a thick, trapezoidal-shaped clay sidewall (method C of Fig. K-4.2) is considered. It is assumed that the sidewall slope would be reduced from 1:2 to 3:1 by use of methods A and B. If the clay sidewall were thick enough, a greater slope should be stable; it is assumed that a wall 6 m thick at the top would support a 1:1 slope. The conceptual mine and methods A, B, and C for options (1) and (2) are shown in Figure K-4.2.

Use of option 1 would require movement of earth calculated as follows:

Method A: L = 556 m

Volume to be removed = 4(1/2 x 30 x 90 x 556) + 8[5/6* (1/2 x 30 x 90 x 90)] - 4(1/2 x 30 x 15 x 556) - 8[5/6(1/2 x 30 x 15 x 15)] = 3.3 x 10^6 m^3

Method B: L = 706 m

Volume to be added = 4(1/2 x 30 x 90 x 556) + 8[5/6(1/2 x 30 x 90 x 90)] - 4(1/2 x 30 x 15 x 706) - 8[5/6(1/2 x 30 x 15 x 15)] = 3.2 x 10^6 m^3

Method C: L = 598 m

Volume to be added = 4(1/2 x 30 x 30 x 556) + 8[5/6(1/2 x 30 x 30 x 30)] - 4(1/2 x 30 x 15 x 598) - 8[5/6(1/2 x 30 x 15 x 15)] + 4(6 x 30 x 622) = 4.5 x 10^5 m^3 .

In a similar fashion it may be shown that for option (2):

Method A: L = 604 m; volume to be removed = 1.8 x 10^6 m^3

Method B: L = 714 m; volume to be added = 1.7 x 10^6 m^3

Method C: L = 664 m; volume of clay = 6.9 x 10^5 m^3 .

In evaluating costs, it is assumed that restoring of the mine would be required under applicable regulations; consequently, the costs assigned to tailings disposal are only those above normal mine restoration costs that are required for the program. Specifically, the return of backfill to the mine is prorated as indicated above, and full costs of grading, compacting, sidewall cutting, liners, etc., are included. For both options, an initial dewatering of the mine is undertaken at a cost of $100,000.

Under option 1, the bottom of the pit would be dewatered at a cost of $100,000 and compacted; compaction of a horizontal surface should present no problems, and the minimum unit cost of $2600/ha is applied.[13] The areas for methods A, B, and C are given by L^2, yielding costs of:

Method A: Area = 5.2 x 10^5 m^2; cost = $140,000

Method B: Area = 5.2 x 10^5 m^2; cost = $140,000

Method C: Area = 4.0 x 10^5 m^2; cost = $100,000

Preparation of the sidewalls by method A would require the removal of 3.3 x 10^6 m^3 of overburden; a unit cost of $1.20/$m^3$ is assumed. No compaction of the cut wall would be necessary, so the cost of preparation of the sidewalls by use of method A would be $3.96 million.

Preparation of the sidewalls by method B would require the addition of 3.2 x 10^6 m^3 of fill, and sloping and compaction of the fill to the proper slope. For reasons given above, no charge is assessed for the fill, but shaping and compaction on the slope at a unit cost of $1.25/$m^3$ is taken, yielding a cost of $4.0 million.

Preparation of the sidewalls by method C could require the excavation, hauling, and emplacement of 4.5 x 10^5 m^3 of clay. The cost of installing the clay sidewall has been estimated to be $2.55/$m^3$; so that the cost of preparing the sidewalls by method C would be $1.15 million. If the clay had to be hauled from an offsite pit, the cost could be increased substantially. If a mined clay, such as bentonite, were purchased, the cost could be in the range of $7.00/$m^3$, increasing the cost of emplacing the clay sidewalls severalfold.

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*The factor 5/6 is correct to within a few percent; the resultant error is negligible.

Two types of liners may be used for both options 1 and 2: 30-mil hypalon at a cost of $\$6.90/m^2$ or clay (1-m thick) at $\$2.55/m^2$. If a hypalon liner is used in the tailings impoundment, the staff has assumed that no evaporation pond will be necessary. In this case, evaporation will be directly from the tailings pit, and the hypalon will inhibit any seepage of tailings solutions. However, an evaporation pond will be needed in the case of clay-lined tailings impoundments, assuming that clay will have seepage-inhibiting qualities not as good as hypalon; evaporation then will be from both the tailings area and the evaporation pond.

The areas to be covered with liners in the tailings impoundment under methods A, B, and C, respectively, would be: 5.2×10^5 m^2; 5.2×10^5 m^2; 4.0×10^5 m^2. Thus the costs for hypalon lining would be \$3.59 million, \$3.59 million, \$2.76 million (for method A, B, and C, respectively); and for clay lining would be \$1.33 million for A or B, \$1.02 million for C.

The total costs for preparation of the basin and lining using method A would be \$9.03 million if a hypalon liner were used, and 6.77 million for clay. For method B, the costs would be higher by \$0.04 million. For method C, the total costs for preparation of the basin and liner would be \$5.28 million for hypalon lined, and \$3.54 million for clay lined.

Volumes of bottom fill under option 1 are estimated to be 2.75×10^6 m^3, 2.75×10^6 m^3, and 2.60×10^6 m^3 for methods A, B, and C, respectively. Corresponding costs, using the unit costs as explained above, are \$1.24 million, \$1.24 million, and \$1.17 million.

The above costs are for option (1), under which the entire open pit mine would be prepared to receive the tailings. Under option 2, the mine would be filled with compacted overburden to above the water line, a total depth of 8 m of fill, before the sidewalls were prepared and the liner emplaced. Dewatering at a cost of \$100,000 would be necessary during the emplacement of overburden. The volume of fill required is slightly different in the three cases, because of the different values of "L" assumed. For methods A, B, and C, respectively, the volumes would be 2.88×10^6 m^3, 4.03×10^6 m^3, and 3.57×10^6 m^3. The costs of emplacement and compaction of these volumes of fill, at a unit cost of $\$0.90/m^3$, would be \$2.59 million, \$3.63 million, and \$3.21 million. (These costs are based on deposition and compaction of one-meter layers; if two-, three-, etc. meter layers could be used, the resulting costs would be one-half, one-third, etc., of those given.)

The costs for preparation of the sidewalls are computed as for option (1); for methods A, B, and C, the costs would be \$2.16 million, \$2.13 million and \$860,000. Again, the areas to be covered by the liners are slightly different; for A, B, and C, they are 5.3×10^5 m^2, 7.1×10^5 m^2, 5.4×10^5 m^2. The costs for a hypalon liner at $\$6.90/m^2$ are \$3.66 million, \$4.9 million, and \$3.73 millions for methods A, B, and C, respectively; for a clay liner (1 m thick) at $\$2.55/m^2$ are \$1.35 million, \$1.81 million, and \$1.38 million.

Total costs for preparing the basin under option 2 and using method A would be \$8.51 million, if a hypalon liner were used, and \$6.2 million if clay lined. For method B, the costs would be \$10.76 million and \$7.67 million. For method C, the costs are are \$7.9 million if hypalon lined and \$5.55 million if clay lined.

After the mine pit had been prepared by use of one of the options and methods discussed above, the tailings slurry would be deposited through a pipeline. Because the basin prepared with hypalon is designed to inhibit seepage of the tailings solution better than clay, it is likely that it would be necessary to remove excess water only from the clay-lined pits. This might be accomplished by various means; a floating decant system is selected for this analysis. The cost of such a system is estimated to be \$100,000. The excess water removed would then be evaporated from a 27-ha pond, costing about \$2.88 million, including restoration of the pond area. The staff has assumed a standard evaporation pond lined with hypalon will be used. The costs of this operation are common to all of the variations. As indicated above, the staff has assumed that no evaporation pond will be necessary, if the tailings impoundment is lined with hypalon.

After the tailings were sufficiently dry, they would be covered with a cover of 6 m earth fill and 0.2 m of topsoil (see Sec. 8.4.2). Of the costs of the covering operation, only the cost of depositing at $\$0.45/m^3$ is assessed to the tailings management scheme. The costs of earth cover vary slightly among the options, because of slight differences in the area to be covered. For option (1), the areas for methods A and B would be about 5.4×10^5 m^2; that for method C would be 3.8×10^5 m^2. The corresponding costs would be \$1.46 million each for A and B and \$1.03 million for C. For option (2), the areas for methods A and B would be 5.4×10^5 m^2; that for method C would be 4.7×10^5 m^2. The corresponding costs would be \$1.46 million each for A and B and \$1.26 million for C.

A compilation of the costs for Alternative 2 is presented in Table K-4.3. It is important to note that while these costs are intended to be representative of the various possibilities presented here and analyzed for this alternative, other operations exist and may be used to accomplish the same general disposal system discussed here. Hence, depending on which specific items or operations are included or excluded from the overall system, costs may vary accordingly.

Table K-4.3 Estimated Costs for Alternative 2 (in $1000)

Feature	Option 1			Option 2		
	Method A	Method B	Method C	Method A	Method B	Method C
Compaction of pit bottom (Includes mine dewatering)	1,480	1,480	1,370	2,690	3,730	3,310
Preparation of sidewall	3,960	4,000	1,150	2,160	2,130	860
<u>Liner</u>						
Clay	1,330	1,330	1,020	1,350	1,810	1,380
Hypalon	3,590	3,590	2,760	3,660	4,900	3,730
Floating decant pump	100	100	100	100	100	100
Evaporation pond	2,880	2,880	2,880	2,880	2,880	2,880
Emplacement of cover	1,460	1,460	1,030	1,460	1,460	1,260
<u>Total costs</u>						
Clay liner/with evap. pond	11,210	11,250	7,550	10,640	12,110	9,790
Hypalon liner/no evap. pond	10,490	11,530	6,310	9,970	12,220	9,160

4. ALTERNATIVE 3 (Fig. K-4.3)

Under Alternative 3, an abandoned mine pit would be used for tailings disposal; the pit bottom would be backfilled (8 m) to above the water table as in alternative 2, and a liner (either PVC or clay) above the fill installed. It is assumed that no hypalon liner would be needed in the tailings pit, since tailings would have been dewatered. In the case of belt filtering, the tailings would be dried sufficiently so that no further water drainage would occur on deposition in the pit; however, further in situ drying might be necessary, before heavy machinery could be operated on the tailings. On cessation of operations, the tailings would be covered with 6 m cover to surface level, and the surface restored. Since restoration of the mine would be required in any case, costs are estimated as in Alternative 2.

The tailings would be dewatered either on a vacuum belt filter (Section 5 of Appendix K-2) to about 20% water, or over an in situ dewatering system (Section 2 of Appendix K-2) installed in the tailings pit. An evaporation pond would be necessary to dispose of all solution in excess of that which could be recycled. In order to allow sufficient surface for evaporation of liquids due to dewatering, the 40-ha hypalon-lined evaporated pond, costing $4.47 million, has been assumed. The cost of a 64-m^2 belt filter installed is estimated at $460,000. As in Alternative 2, with the tailings layer at 15 m thick and 43 ha average area, the disposal pit in this alternative is estimated to have a bottom area of approximately 41 ha. The cost of an in situ dewatering system (which would be roughly 42 ha in area) would be approximately $680,000 (see Appendix K-2). Furthermore, if a belt filter were used, costs of hauling the drained tailings to the pit would add approximately $5.9 million.

The pit preparation cost for each system would add 3.29 million. Only the bottom 41 ha of the pit would be lined, resulting in costs of $1.07 million for clay and $2.06 million for PVC. Covering with 6 m earth would cost $2.7 million; as stated, other costs of the operation are attributed to mine restoration. The costs are summarized in Table K-4.2 and in Chapter 11.

5. ALTERNATIVE 4 (Fig. K-4.3)

Under Alternative 4, a naturally occurring low permeability bed of soft shale or clay is assumed to be available near the mill. The tailings pit would be specially excavated into the bed, and untreated tailings would be deposited therein.

As a consequence of the impermeable walls and floor and the low water seepage rate, an increased free water surface over that of Alternative 1 would be available for evaporation (see App. E). The time required for the tailings to dry internally to the point that heavy machinery for covering with clay or earth could be used on the surface of the tailings would be about five years after operations cease. It is assumed that during this period, water spraying would be used to control dusting.

With the increased evaporating surface of the tailings impoundment, it is possible that the evaporation pond needed under this alternative may be smaller than that used for Alternative 2. In view of the uncertainty, however, the same evaporating area as Alternative 2 is used.

The other costs would be as follows. A depth of 11 m and area of 80 ha are assumed for the pit. Excavation costs are normally taken as $1.20/m^3; however, in shale, ripping may be necessary at a cost of about $4.00/m^3. The total cost for excavation and compaction of bottom clay would be $10.77 million. Costs for final covering with 3 m earth are computed for a compacted cover; the pit is assumed to be covered with material excavated from, and stored adjacent to, the pit itself. Costs for redepositing, spreading, and compacting the cover material is estimated at $1.00/m^3, for a total of $2.4 million.

6. ALTERNATIVE 5 (Fig. K-4.3)

In Alternative 5, the tailings impoundment is prepared in staged sections during operation, so that material excavated from one section can be used as cover material over tailings disposed into an earlier section. This will allow for avoiding second handling of the excavated overburden over most of the pit. The staff has assumed that one-third of the pit is covered with material through double handling; i.e., one-third of the pit is excavated, and the excavated material is stored next to another section of the pit before being redeposited. The cover will be 3 m thick and will be compacted. Therefore, the cost of covering one-third of the pit will be $1.00/m^3, for redepositing, spreading, and compacting. Two-thirds of the pit will thus be covered with compacted material by single-handling, at $0.45/m^3 for spreading and compacting only. The general form and dimensions of each trench are shown in Figure 8.9. The pit would be lined either with hypalon or 1 m of clay and would be covered with 3 m of earth. The pit would be approximately 16 km long, folded into a 1060-m by 1200-m rectangular area. The width of the flat bottom would be 20 m, and the total width of the top 70.4 m for the hypalon liner and 74.4 m for

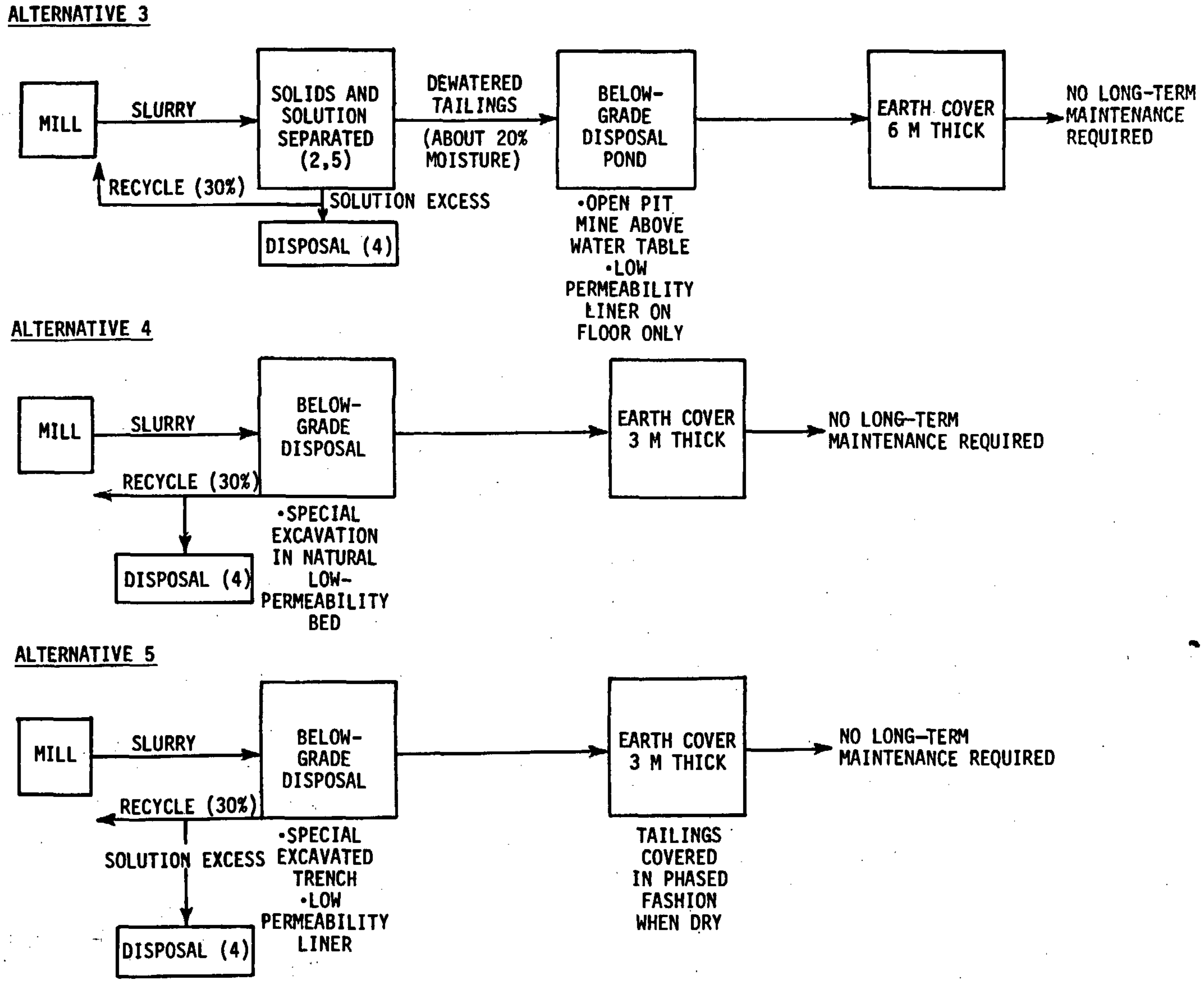


Fig. K-4.3. Tailings Treatment Flow Sheet for Alternatives 3, 4, and 5.

the clay liner. The excavated depth would be 12.6 m for hypalon and 13.6 m for the clay liner. The tailings depth would be 10 m.

For excavation and lining of the pit, an initial section sufficient for about five years' production and drying of tailings would be needed, with the remainder constructed as operations required. An inexpensive temporary dike would be necessary to separate construction areas from deposition areas, and a pumping system and evaporation pond (for use with clay-lined tailings pit) would be necessary to remove water from the trench and allow the tailings to dry. Covering of the tailings with earth could follow as soon as a section of tailings was dry enough to support heavy machinery. The estimated time is about one year. Construction, filling, covering, and restoring of the trench would follow in a continuous sequence.

The cost of excavation is taken to be $1.08/m^3$,[11] with 9×10^6 m^3 and 1.0×10^7 m^3 required for the hypalon- and clay-lined pits, respectively. Corresponding costs would be $10.0 million and $10.8 million. The total lined area would be 1.2×10^6 m^2, for costs of $8.25 million and $3.06 million for hypalon and compacted clay liners, respectively. The lined evaporation pond (Sec. 4, App. K-2) would cost $2.88 million and a centrifugal pump to remove water from the trench would cost on the order of $10,000. A total of 112 ha and 118 ha for the hypalon- and clay-lined pits, respectively, would have to be covered with 3 m of earth. The total costs (computed as for Alternative 4) would be $2.23 million and $2.12 million, respectively. Surface restoration and revegetation would cost $560,000 and 590,000, respectively, for hypalon- and clay-lined pits. The costs are summarized in Table K-4.2 and in Chapter 11.

7. ALTERNATIVE 6 (Fig. K-4.4)

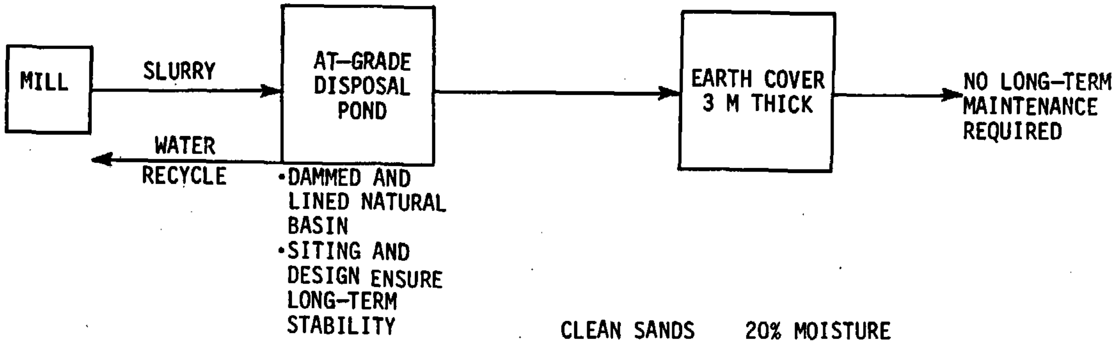
Under Alternative 6, a retaining pond would be created by building a dam across a natural basin. The basin would be located so that little or no upstream drainage would come into the storage area, and the structure could be expected to have long-term stability against washing and erosion. The bottom of the area would be prepared by removal of 0.60 m of topsoil from the total area (~ 86 ha), and the tailings area (80 ha) would be lined with hypalon or one meter of clay. A clay-cored tailings dam would be built, chemical spraying for interim dust control (Sec. 4 of App. K-1) would be used during the operations, and the top eventually would be covered with the standard cover.

The area preparation costs would be $620,000. The tailings dam is taken to be 10 m high, 1000 m long, 57 m wide at the base, and 7 m wide at the top. The clay core would occupy the central 7-m width of the dam and would be keyed 4 m deep into the foundation surface. The costs of deposition and compaction of clay and of earth fill are $2.55/m^3$ and $2.45/m^3$, respectively. The clay core would have a volume of 75,000 m^3, for a cost of $190,000; the earth fill would have a volume of 191,000 m^3, for a cost of $470,000 (total of $660,000). The basin could be lined with one meter of compacted clay at a cost of $2.04 million, or with hypalon at a cost of $5.5 million. In the case of a clay-lined pit, an evaporation pond (27 ha) would be required, at $2.88 million. The sloping surface of the natural basin may make chemical dust stabilization advisable in this alternative, and costs for this are included. Cover costs are as in Alternative 1 for $4.2 million. Reclamation of the cover will cost $400,000. In addition, the outer side of the dam would be recontoured, following termination of operations, to a gradual slope (10 horizontal to 1 vertical). Costs for recontouring is estimated at $620,000. Rock cover (0.5 m thick) will be provided at a unit cost of $12/m^3$ (see App. K-6, Sec. 1.5) for a cost of $600,000. The total cost for reclamation and stabilization in this alternative is thus $1.62 million.

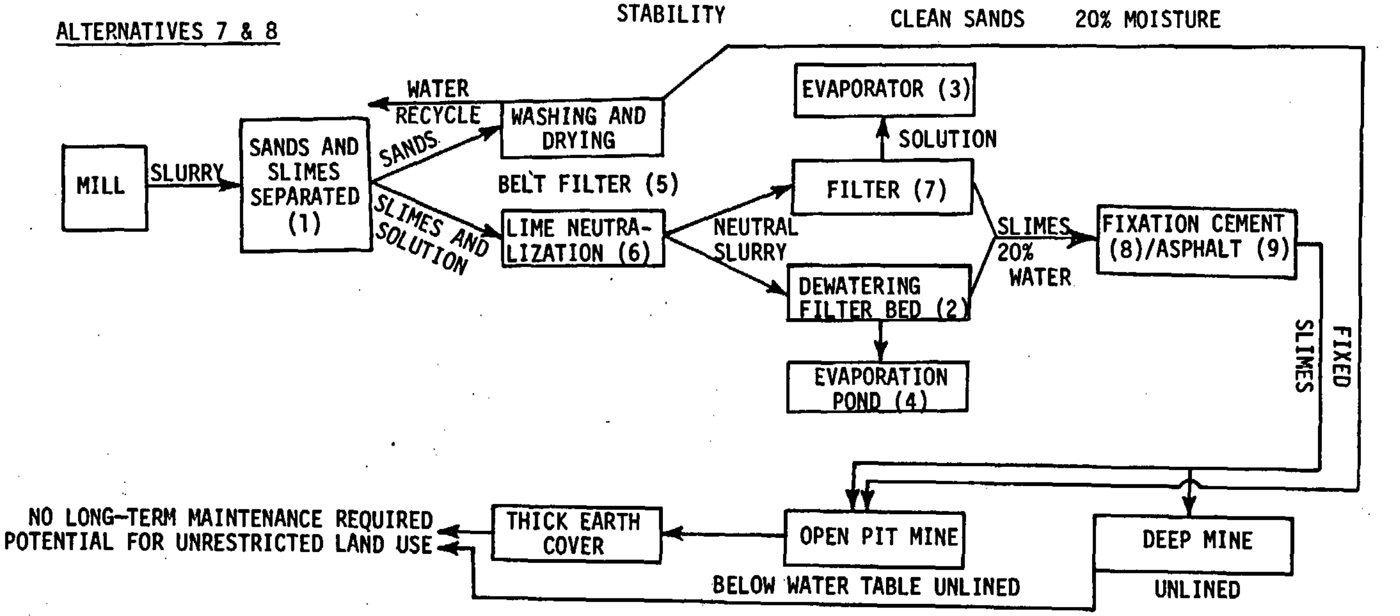
8. ALTERNATIVE 7 (Fig. K-4.4)

Under the assumptions of Alternative 7, the sands and slimes would be separated, the sands washed with clean water, partially dried, and deposited in an unlined and unbackfilled open mine pit. The slimes, along with aqueous mill wastes, would be neutralized with lime (Sec. 6 of App. K-2), and the solids, including newly formed precipitates, would be separated from the water and partially dried. Optional methods of drying slimes are considered. These methods are the use of thickeners and vacuum disc filters (Sec. 7 of App. K-2), with a fossil-fueled evaporator (Sec. 3, App. K-2) to dispose of water, and a combination of a dewatering filter bed (Sec. 7, App. K-2) with a separate evaporation pond (Sec. 4, App. K-2) for water disposal. When sufficiently dry, the slimes would be combined with Portland cement (1 part cement to 5 parts tailings) or asphalt (1.5 parts asphalt to 2 parts tailings) and deposited in the open pit mine adjacent to sand deposition areas, where the slurry would harden. Both the fixed slimes and the washed sands are assumed to be resistant to leaching and can be exposed to groundwater in contrast to earlier alternatives. On completion of tailings operations, the mine pit would be backfilled with overburden and the surface restored.

ALTERNATIVE 6



ALTERNATIVES 7 & 8



[NOTE: For Alt. 7, both sands and slimes would be deposited in an open pit mine; for Alt. 8, sands would be deposited in an open pit mine, slimes in a deep mine.]

Fig. K-4.4. Tailings Treatment Flow Sheet for Alternatives 6, 7, and 8.

If an evaporator were used to remove water, the condensate could be used to wash sand; however, if the slurry water were not recovered, a source of clean water would have to be obtained. The type of drying used for the slimes would depend on the chemical and physical properties of the slimes and would have to be determined by tests. Filtration rates for certain slimes are impractically slow, or the water cannot be removed by filters to a level where direct mixing with asphalt or cement is feasible.[2] In such cases, the outdoor slimes-drying area and separate, lined evaporation pond may be the only practical drying method.

The costs of each of the steps required are listed in Appendix K-2. These steps and the pertinent sections of Appendix K-2 in which they are discussed are as follows:

a. Separation of sands from slimes and the bulk of the solution (Sec. 1),

b. Washing and partial drying of the sands (Sec. 1),

c. Lime neutralization of the slimes and solution (Sec. 6),

d. Separation of the slimes solids from liquid on a vacuum disc filter (Sec. 7a) or in a drying bed (Sec. 7b),

e. Disposal of excess solution in a fossil fuel heated evaporator (Sec. 3) or in an evaporation pond (Sec. 4),

f. Fixation of the partially dried slimes (20% water) in asphalt (Sec. 9) or in cement (Sec. 8).

9. ALTERNATIVE 8 (Fig. K-4.4)

In Alternative 8, tailings would be treated as in Alternative 7 and deposited in a deep mine rather than the open pit mine considered above. Deposition of the tailings through existing tunnels would probably not be possible (the ore bodies are above the access tunnels) and several new 0.4-m boreholes would have to be sunk for tailings deposition at an estimated cost of $1,880,000 each.

10. ALTERNATIVE 9 (Fig. K-4.5)

Under Alternative 9, the tailings would be released from a nitric acid mill (Sec. 8.4.10). The tailings disposal method selected is that of Alternative 6 (dammed natural basin); however, a thinner cover can be used since it is assumed that about 90% of the radium and radon would be removed. In addition to the tailings, about 50 tons per day of dried nitric acid leachate, which contains most of the radium and thorium of the ore, would be produced.[14] The material would be calcined to the oxides before release in order to conserve nitric acid and also to prevent the release of nitrates. The wastes would be fixed in asphalt or cement and deposited in a special pit with a 10 m thick final cover. The pit is taken to be 2 ha in area and 17 m deep.

The costs of the tailings pit would be identical with those of Alternative 6, except that a 1.5 m earth cover can be used to produce the same radon flux at the surface.

The cost of the cover would be $2.1 million. Capital costs for cement and asphalt fixation would be $140,000, on the average.[14] The construction costs for the special pit are estimated to be $300,000. Restoration costs for the special pit would be $10,000.

References

1. Dames and Moores, "Environmental Report, Bear Creek, Wyoming," prepared by Dames and Moore for Rocky Mountain Energy Corp., 1975.

2. Rocky Mountain Energy Co., "Analysis of Alternatives for Mill Tailings Disposal," Bear Creek Uranium Project, 1976.

3. U.S. Nuclear Regulatory Commission, "Final Environmental Statement, Bear Creek Project," Docket No. 40-8452, NUREG-0129, January 1977.

4. U.S. Nuclear Regulatory Commission, "Draft Environmental Statement, Sweetwater Uranium Mill, Docket No. 40-8584, December 1977.

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ALTERNATIVE 9

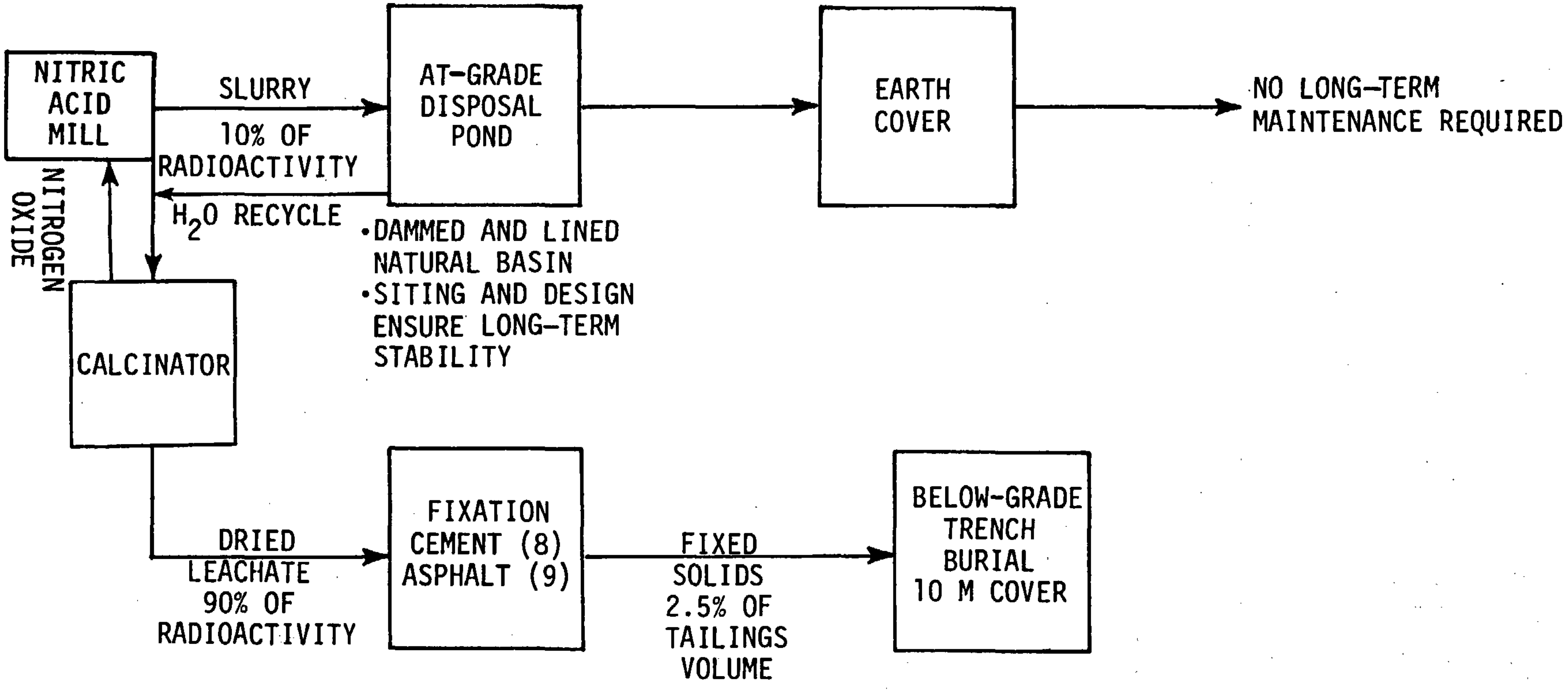

Fig. K-4.5. Tailings Treatment Flow Sheet for Alternative 9.

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7. D. Appolonia Consulting Engineers, Report 2, "Tailings Abandonment and Stabilization," prepared by D'Appolonia Consulting Engineers, Inc., for Western Nuclear Corp., Split Rock Mill, September 1977.

8. U.S. Environmental Protection Agency, "Environmental Analysis of the Uranium Fuel Cycle, Part IV, Supplementary Analysis, 1976," EPA 520/4-76-017, 1976.

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10. Bond Evaluation to State of Utah for Humeca Uranium Mill, 13 September 1976.

11. R. S. Means Co., Inc., "Building Construction Cost Data," Duxbury, MA, 1978.

12. Letter from E. Will, Dames and Moore, to R. Adrian, Atlas Minerals, "Riprap Design Study," enclosure. 2 October 1978.

13. Dames and Moore, "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in the Western United States," Dames and Moore report prepared for Argonne National Laboratory, July 1977.

14. D. A. Brobst and W. P. Pratt, "United States Mineral Resources," U. S. Government Printing Office, 1973.

APPENDIX K-5 COSTS OF ALTERNATIVE METHODS OF TRANSPORT OF TAILINGS SLURRY

In the discussion of tailings alternatives, it has been assumed that the disposal area would be close to the mill, and the delivery costs could be charged to mill operations. Many of the alternatives would require special locations, which could make some extra tailings transport necessary. For the model mill, an 18-cm pipeline would be required. Cost estimates (1980 dollars, escalated from ref. 1) have been made for a 40-km-long pipeline, with lower unit costs for longer distances.[1] The capital costs were $1.62 million, resulting in fixed charges of $275,000 per year. Operating costs were 2.2¢/MT-km (3.3¢/ST-mile), resulting in total costs [fixed charges = $1.2¢/MT-km (1.8¢/ST-mile)] of 3.4¢/MT-km (5.0¢/ST-mile). Truck transport costs on a similar scale were 6.3¢/MT-km (9.4¢/ST-mile).[1] Right-of-way costs are estimated as $1400/km ($2300/mile).[1] Assuming linearity of costs with distance, for the 1800 MT/day mill and a 16-km distance of the mill to the disposal site, then capital, annual and lifetime total costs would be $650,000, $370,000, and $6.2 million, respectively.

Reference

1. Dames and Moore, "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transportation Systems in the Western United States," Dames and Moore report prepared for Argonne National Laboratory, July 1977.

APPENDIX K-6. COSTS OF ALTERNATIVE COVERINGS FOR TAILINGS DISPOSAL AREAS

1. NATURAL COVERS

For purposes of comparing differences in noncover aspects of the disposal alternatives, the covers for the tailings disposal alternatives of Appendix K-4 have been a fixed 3 m of soil, the "standard cover," to meet the 2 pCi/m^2-s radon flux limit. This would require a soil which could have long-term moisture retention capacity of about 9% or more. Variable factors which can lead to the the need for different thicknesses and different costs for tailings cover are evaluated in this section. Costs for covering tailings disposal areas are dependent on a number of site-specific factors, the primary ones being attenuation properties of the cover material and hence, the amount of cover material needed; availability of cover materials; area of the tailings pile; ore quality; and distribution of sands and slimes in the tailings disposal area. The effects of varying each of these factors on cost are treated in turn, in the following discussion. The thicknesses and costs of obtaining various degrees of attenuation by use of model mill soil with several moistures, and thus, differing radon retention properties are shown in Table K-6.1. (See Fig. K-6.1 for a graph display of the cost variation.)

1.1 Radon Attenuation Properties

Soil properties affecting radon attenuation are highly variable; transport of radon through soil depends mainly upon soil moisture. Therefore, cover thicknesses (and associated costs) needed to yield a given radon exhalation rate will vary, mainly depending on moisture, as discussed in Chapter 9. The cover thicknesses and costs of seven different typical moistures have been evaluated for illustrative purposes. The attenuation properties (a measure of which is a soil's "diffusion coefficient," a parameter used in equations for predicting radon attenuation) of these typical soils illustrate the range of attenuation properties expected of real soils.

In Table K-6.1, it is shown that the cost for covering the tailings with soil D would be $56,000 per hectare of tailings disposal area. For the model mill, this would represent a cost of about $4.5 million. Tailings cover costs for this soil type would be equivalent to about 0.75% of the price of U_3O_8, and about 0.08% of the cost of generating electricity. As mentioned above, if soil G with good radon attenuation characteristics is available, then only 2.2 m (7 ft) is needed to meet the proposed radon limit, and costs would drop to $3.1 million, or about 0.5% of the price of U_3O_8 produced. On the other hand, if soil A with poor radon attenuation characteristics is used, the costs would be about $7 million, or about 1.2% of the price of U_3O_8. [To meet the minimum thickness requirement, 3 m (10 ft) of soil would be required, at a cost of $4.2 million.] The staff believes these costs span the range of what will be encountered in most situations.

1.2 Availability and Unit Cost of Cover Material

The costs for cover material are assumed to be only those of excavation, hauling, depositing, and contouring. The soil material itself is assumed to be essentially "free." For common overburden and soils, it is reasonable to assume such materials can be found onsite.

In the staff analysis of costs, overburden stripped during mining and returned to an open pit is considered a mining cost, and as such, is considered to be "free," in the context of tailings disposal. Such costs would be incurred regardless of requirements for mill tailings disposal, because existing mine reclamation laws would require it.

As is illustrated by the range of estimates of the costs of cover for alternative tailings disposal programs, varying unit costs for the operations involved can result in different total costs. If the cover operation merely involves "pushing" overburden over the tailings, the costs could be considerably lower than if overburden must be excavated, hauled, spread over the tailings and compacted.

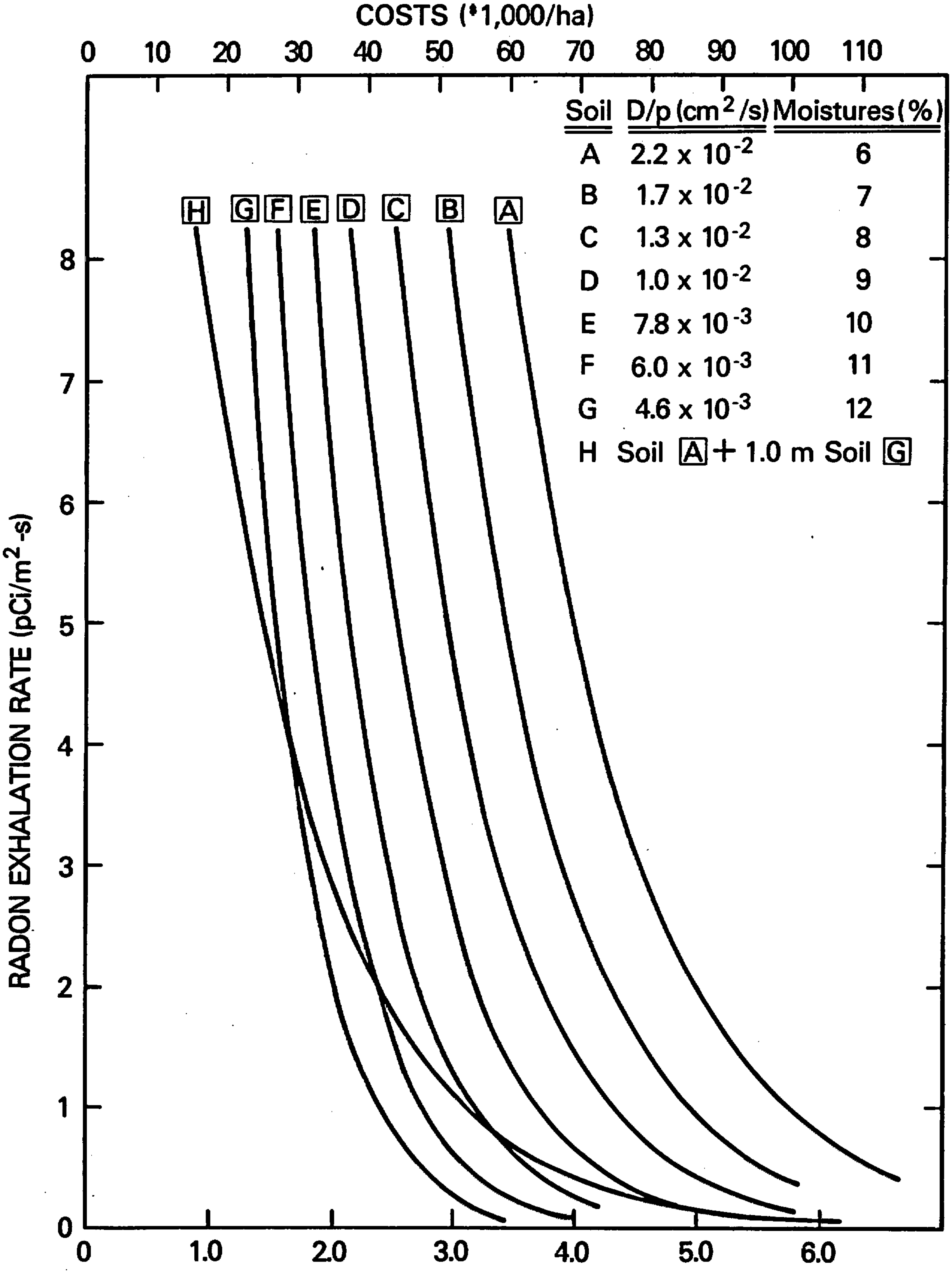
1.3 Variation of Tailings Area and Ore Grade

For a given soil cover type and thickness, costs for tailings coverings will also vary with the area of the tailings pile and the ore grade. For a given volume of tailings, the surface area to be covered will depend on depth of the tailings pile. The cost for covering model mill tailings with soil A was estimated to be $7,000,000, on the assumption that the tailings will have a specific activity of 280 pCi/g, and an exposed area of 80 ha (200 acres). If the thickness of the tailings pile for the model mill were increased to 17 m (56 ft), then the cost of tailings covering would drop to $3,6000,000. In a similar manner, tailings over costs

Table K-6.1. Costs of Attenuating Radon Flux as a Function of Thickness of Different Soil Coverings for the Model Mill

Flux (pCi/m^2-s)	Costs (thousands of dollars per hectare) and Thicknesses (meters) of Different Soils									
	Soil A		Soil C		Soil D		Soil E		Soil G	
	Cost[a]	Thickness	Cost	Thickness	Cost	Thickness	Cost	Thickness	Cost	Thickness
100	15.8	0.9	10.5	0.6	8.75	0.5	7.0	0.4	3.5	0.2
10	57,8	3.3	43.8	2.5	38.5	2.2	33.3	1.9	24.5	1.4
5	70.0	4.0	52.5	3.0	45.5	2.6	40.3	2.3	29.8	1.7
3	80.5	4.6	59.5	3.4	52.5	3.0	45.5	2.6	35.0	2.0
2	87.5	5.0	66.5	3.8	56.0	3.2	49.0	2.8	38.5	2.2
1	99.8	5.7	75.3	4.3	64.8	3.7	57.8	3.3	43.8	2.5
0.5	112.0	6.4	85.8	4.9	73.5	4.2	64.8	3.7	49.0	2.8
0.1	141.8	8.1	106.8	6.1	96.3	5.5	82.3	4.7	63.0	3.6

[a] Cost basis: \$1.75/m^3 of cover.



Soil	D/p (cm^2/s)	Moistures (%)
A	2.2×10^{-2}	6
B	1.7×10^{-2}	7
C	1.3×10^{-2}	8
D	1.0×10^{-2}	9
E	7.8×10^{-3}	10
F	6.0×10^{-3}	11
G	4.6×10^{-3}	12
H	Soil A + 1.0 m Soil G	

Fig. K-6.1. Costs of Reducing Radon-222 Exhalation Rate for Various Cover Types.

for the model mill would approximately double, if the tailings pile thickness were halved to 4.4 m (14 ft).

The effect of ore grade is not so direct, since costs depend both on the thickness and area of the cover, which are affected differently by the ore grade. An example should make the situation clear: For the model mill, an ore grade of 0.10% U is assumed, equivalent to a specific activity of 280 pCi/g, which, in turn, is assumed to be equivalent to a radon flux of 280 pCi/m^2-s. The assumed ore grade, with the assumed capacity of the mill, results in a production of an average of 1.4MT/day (1.5 ST/day) of uranium, and 1800 MT/day (1985 ST/day) of tailings. The mill's lifetime production of dried tailings, when spread over the assumed area of 80 ha (200 acres), would have a depth of 8.73 m (29 ft). If, instead, the ore grade were assumed to be 0.05% (equivalent to a radon flux of 140 pCi/m^2-s) and the uranium production were maintained at 1.4 MT/day (1.5 ST/day) (so that the lifetime revenue is unchanged), the mill would then produce 3600 MT/day (3960 ST/day) of tailings, equivalent to a lifetime production of 1.05 x 10^7 m^3 (13.13 x 10^6 yd^3) of dried tailings. If this volume were spread over 80 ha (200 acres), the depth would be 13.1 m (42.9 ft). On the other hand, if the depth were maintained at 6.54 m (21.5 ft), the area occupied would be 160 ha (400 acres). In either case, the thickness of the cover of soil E required to reduce the radon flux at the surface to a given level, such as 2 pCi/m^2-s would be 2.4 m (7.9 ft) (see Fig. K-6.1). For the 80 ha (200 acre) area, the cost of emplacing the cover would be $3.92 million; for the 160 ha (400 acre) area, $7.84 million.

These two situations represent the extremes; in practice an intermediate situation would exist. For purposes of illustration, it will be assumed that the increase (or decrease) in volume of the pile will be shared proportionately by increases in area and depth (i.e., $\Delta H/H = \Delta A/A$, where H is the height and A is the original area of the tailings). This assumption yields a depth of 9.25 m (30.3 ft), an area of 113 ha (283 acres), and a cost of $4.75 million for an ore grade of 0.05% uranium. Other cases, computed in the same manner, are presented in Table 12.4.

1.4 Distribution of Sand and Slime Fractions

The manner in which the sand and slime fractions are distributed in the tailings pile will affect the cover thicknesses needed and, therefore, the costs. If tailings are deposited in such a fashion that slimes are layered below sands, as opposed to even distribution of these fractions, as might be the case in Alternative 5, the reduction of thickness required to reach the proposed limit using soil E could be as much as about 1 m (3 ft), and associated cost savings of about $1.4 million in application of cover material could be realized.

1.5 Vegetation and Riprap

The covers are assumed to be restored by capping with "topsoil," which is seeded with native grasses, and watered until the vegetation is established. Quoted costs vary, and the staff has chosen an average value of $5000/ha. In some areas, such restoration may not be possible, because sufficient vegetation cannot be established. In this event, stabilization by riprap may be necessary. Again, quoted costs vary (see App. K-4), and the staff has chosen a unit cost of $12/m^3, on the basis that ordinary riprap available at the site would be adequate; assuming an average depth of 0.5 m, this is equivalent to $60,000/ha.

Costs for rock cover in several different areas near uranium mills were investigated. Generally, mining costs for the rock are similar at all areas, where such rock is available. Costs for mining and grading of the rock ranged from $4.25 to $4.60 per ton, and areas around San Antonio, Texas, Rapid City, South Dakota, and Casper, Wyoming, were investigated. These costs are applicable to both coarse aggregate and medium aggregate. However, some quarries are not equipped to produce the coarse aggregate specified here, as this is somewhat larger sized than the maximum size used for normal concrete aggregate.

Proximity of a source of rock, with respect to the uranium mill, will have a large influence on the cost of covering tailings piles. Generally, costs for hauling rock are approximately $0.12 per ton mile at present, with haul distances in the 20- to 40-mile range. Longer haul distances will slightly decrease the unit costs, while shorter haul distances can greatly increase the ton/mile costs for hauling.

At an average cost of $4.50 per ton for mining, crushing, and grading of coarse and medium aggregate, and assuming a typical haul distance of 30 miles, the cost for rock at the site of the model mill would be approximately $8.10 per ton. Typically, in-place densities of the coarse and medium aggregate will range from 100 to 110 pounds per cubic foot, or 3,500 to 3,900 pounds per cubic meter. Costs for installation (dumping, spreading, and rolling) of the rock on the tailings pile is estimated at $1.00 per cubic meter. Therefore, total installed costs of the rock cover at the mill site is estimated at $16.00 per cubic meter (including hauling), with a range of $12-30/m^3.

2. SYNTHETIC COVERS

The cost estimates for synthetic covers would be similar to those described for liners (App. K-3). The strength and chemical resistance of hypalon would probably not be necessary for a cover; however, the cover might have a greater exposure to oxygen, which generally deteriorates plastic. A protective earth covering at least 1-m thick would be required.

Table K-6.2. Effect of Varying Ore Grade on Tailings Cover Cost

	Tailings			Costs	
Ore Grade (%U_3O_8)	Thickness (m)	Area (ha)	Cover[a] Thickness (m)	Total ($\$10^6$)	Percent of U_3O_8 Price[b]
0.05	9.25	113	2.4	4.75	0.52
0.10	6.54	80	2.8	3.92	0.78
0.15	5.34	65	3.1	3.53	0.39
0.20	4.62	57	3.3	3.29	0.36
0.25	4.14	51	3.4	3.03	0.34

[a] Cover is assumed to be of Soil E.

[b] Taken to be $66/kg (30/lb).

APPENDIX K-7. COSTS OF ALTERNATIVE MODES OF MILL DECOMMISSIONING

Alternative modes of decommissioning are described in Section 8.5, and the environmental consequences of those actions were examined in Section 9.5. The monetary costs of the actions required to return the mill site (excluding the tailings area), the mill buildings, and any offsite contaminated areas to conditions suitable for unrestricted general use are described in this section. It is assumed that no tailings material would have been removed for use in offsite construction and, therefore, that no decontamination of offsite buildings would be necessary.

The alternatives to be considered are: (1) the retention and use of some or all of the buildings and equipment after decontamination, and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to its original state. The abandonment of the mill and site without decontamination and with or without fencing and guards is not considered a viable alternative.

1. DESCRIPTION OF ACTIONS REQUIRED TO IMPLEMENT ALTERNATIVES

On cessation of mill operations, all salvageable equipment would be decontaminated to acceptable levels of surface radioactivity (Table 9.10). Nonsalvageable equipment would be removed from the buildings and buried in the tailings pile. Concrete floors, foundations, sumps, and subsurface piping with unacceptably high levels of uranium and daughter nuclides would be broken up, removed, and buried in the tailings pile. Contaminated earth beneath removed foundations and equipment would be excavated to the required depth and also taken to the tailings pile. The building would be decontaminated; any porous, contaminated material, such as concrete block, would be removed. For Option 1, equipment could be removed from the buildings as desired and the buildings would then be available for general use. For Option 2, the buildings would be removed and uncontaminated foundations broken up and used as fill or riprap on steep or erodible slopes.

Areas outside the buildings and not covered with equipment would be treated identically in the two options. Heavily contaminated areas, such as ore pads and sludge or collection ponds, would be excavated, generally to a depth of several feet, and the dirt removed to the tailings pile. The extensive onsite and offsite areas lightly contaminated by dusts blown from the ore pad, mill, and tailings are expected to be excavated to a relatively shallow depth (4 to 6 inches), with contaminated dirt being taken to the tailings pond. Finally, all excavated areas would be backfilled, graded, topsoil added where necessary, and revegetated.

2. EQUIPMENT AND BUILDING DECONTAMINATION*

Generally, all metal-surfaced equipment can be decontaminated and reused. The types of equipment salvageable include crushers, grinders, rod mills, valves, pumps, steel tanks, and various other special items. For decontamination, simple procedures, such as scrubbing with detergents and sandblasting, have generally been successful.

Soft-surfaced or porous materials (e.g., wood, fiberglass, plastic, concrete, concrete block, or rubber-surfaced equipment) generally cannot be decontaminated economically and must be removed and buried in the tailings area. Electric motors exposed to radioactive solutions usually cannot be decontaminated. In some cases, high-quality lumber used for tank shells can be reused in new uranium mills, but not otherwise.

Mill buildings of bolted, prefabricated steel construction, as assumed for the model mill, have rarely presented any decontamination problems. In some mills, however, large amounts of yellowcake dust or of uranium daughter nuclides have accumulated in inaccessible areas, such as overhead support members or rafters; such hazards must be guarded against during dismantling. In areas where acid solutions are handled, uranium and its decay products have penetrated concrete foundations and the earth below to a depth of several feet. The contaminated foundations and dirt must be removed regardless of whether the entire building is to be reused or removed. In the case of the model mill, it is assumed that extensive areas of concrete and dirt contamination would be present.

Although the decontamination of equipment and buildings is not generally hazardous or difficult, protective equipment is required for working personnel. In addition, since unexpected hazards can occur, competent health physics personnel should be in close supervision during cleaning and dismantling, and all applicable exposure limits must be met.

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*Much of the information in this section is based on communications with representatives of industry and state and federal government agencies.

The costs ascribed to the equipment and building decontamination phase of decommissioning include the dismantlement and burial of nonsalvageable equipment, decontamination of salvageable equipment and buildings, and the removal of contaminated foundations and underlying dirt. No published breakdown of individual costs are available, and the only estimates of total costs obtained were in terms of man-years expended. Reports or estimates for three different mills were 0.005, 0.006, and 0.014 man-years per ton of mill capacity.[1] The value 0.006 is taken as a best estimate, giving 12 man-years for the model mill. The necessary equipment and chemicals would be available in the mill. On the basis of the areas of the leaching and counter-current decontamination tanks, it is estimated that 35,000 square feet of concrete and underlying dirt would be removed to a depth of six feet. Costs of removal ($1.20 per cubic yard) are included in the total for decontamination cited above.

3. REMOVAL OF BUILDING AND SALVAGEABLE EQUIPMENT

In several mills where production has ceased, the salvageable equipment has been sold or transferred to new mills owned by the same company. Much of this equipment is of use in general ore-processing operations and consequently, markets should be available. For the model mill, it is assumed that the salvageable equipment would be removed without cost to the mill operator. A rough estimate is that the salvageable equipment might be worth 10% to 20% of the original value; however, no credit is taken for such value, and it is assumed that this value would offset the removal costs. The initial cost of the salvageable equipment is about one-third of the total cost for the model mill.[2]

Estimated costs for building removal (as in Alternative 2) ranged from $2.40 per square foot for a remotely located, difficultly dissembled building, to a net value of $1.20 per square foot for an easily dissembled building with a nearby market. Industry sources generally have indicated that buildings could be removed at no cost to the company, and this is assumed to be the case for the model mill.[3] The foundations removed could be used as uncontaminated fill or for the riprapping of steep slopes.

4. AREAL DECONTAMINATION

The decontamination and restoration of any area not covered by buildings or exterior mill equipment would be classed as "areal decontamination." Included would be heavily contaminated areas, such as ore pads and sludge or storage ponds, as well as lightly contaminated areas where settled dust from the ore, tailings pile, or mill was the contaminant. The costs would be those of removing the layer of contaminated earth to a depth where concentrations of radioactivity are acceptable (Table 9.10), transporting the contaminated earth to the tailings pond, and then restoring and revegetating the area. Restoration would involve backfilling, regrading, and adding topsoil as necessary.

It is assumed that for the model mill, the ore pad would be the only heavily contaminated area. The pad would have an area of 8 ha (20 acres), and an excavation depth of three feet is assumed.[4] At a removal and burial cost of $1.20 per cubic yard, the total cost would be $120,000.

In the past, the area of light contamination, both onsite and offsite, has varied considerably from mill to mill. A conservative estimate of this area for the average mill is about 300 acres, with a removal depth of six inches.[4] The cost of removal and restoration is taken as $1900 per acre for a total cost of $570,000.

5. MISCELLANEOUS

Continued maintenance costs are not estimated in this analysis. If the tailings pile were not sealed, decontamination would eventually be necessary again, since redeposition of radioactive dust from the pile would continue.

Engineering and contingency costs must also be added, in addition to the costs cited above for decommissioning. Based on a recent study,[4] engineering would be about 6% of the amounts given above, and contingency would be 15%. These costs must be added to the total. The costs, shown in Table K-7.1, are in 1980 dollars, and escalation must be added for future years, if required.

Table K-7.1 Summary of Cost Estimates for Decommissioning[a] (1980 dollars)

Expenditure		Cost
Mill and building decontamination, 12 man-years at $30,000[b] per man-year		$ 360,000
Machinery removal		No cost
Building removal		No cost
Restoration of heavily contaminated area, 100,000 cubic yards of dirt moved at $1.2 per cubic yard		120,000
Restoration of lightly contaminated area, 300 acres at $1900 per acre		570,000
	Subtotal	1,050,000
Engineering, 6% of subtotal		63,000
Contingency, 15% of subtotal		157,000
	TOTAL	$1,270,000

[a] Since building and machinery removal are assumed to have no cost, the costs of Alternatives 1 and 2 are identical. In individual cases, one or the other alternative could be economically preferred.

[b] Costs quoted are operator costs; that is, overhead is included.

References

1. Dames and Moore, "Environmental Report, Bear Creek Project," July 1975.
2. Dames and Moore, "Evaluation of Cost Parameters for Hypothetical Milling Operations," prepared by Dames and Moore for Argonne National Laboratory, July 1977.
3. Letter from Gary Beach, Wyoming Dept. of Environmental Quality, Cheyenne, Wyoming, to F. Vaslow, Argonne National Laboratory, 9 February 1978.
4. Ford, Bacon, and Davis Utah, Inc., "Phase II - Title I Engineering Assessment of Inactive Uranium Mill Tailings," Volumes for Durango, Naturita, Gunnison, Grand Junction, and Rifle, Colorado, Sites, November 1977.

APPENDIX K-8. COST BASES

Costs, as reported in this document, have been separated into the two major categories of capital costs and operation and maintenance costs. Although various systems can be utilized to delineate components of each of the categories, the following specific items have been included, in deriving each of the cost categories for the assessment.

Capital Cost Elements Considered:

Labor for construction
Construction contractor's costs of owning and operating equipment for construction
Materials for construction
Purchased equipment for installation
Construction contractor's general overhead and profit
Taxes on construction equipment and materials (assessed to construction contractor)
Construction contractor's cost for bid bonds, performance bonds and insurance

Operating Cost Elements Considered:

Labor (including fringe benefits and supervision)
Chemicals
Fuel
Power and other purcahsed utility services
Transportation of purchased materials
Maintenance and replacement parts and materials
Maintenance and replacement labor

Cost estimates of this document do not include the elements listed below, principally because these elements can be quite variable. However, for general perspective, possible costs for each element have been estimated as percentages of the reported costs and are shown in parentheses for each element.

Capital Cost Elements Not Considered:

Owner's costs for interest during construction (10 percent of construction costs - depends on time required for construction and interest rates applicable to funding capital)

Owners's costs for engineering (10 percent of construction costs)

Owner's legal and overhead costs for project administration (5 percent of construction costs)

Costs of land areas required for facilities and processes (no estimate - highly variable and site specific)

Operating Cost Elements Not Considered:

Insurance (1 percent of construction costs per year)

Taxes on land and facilities (2 percent of construction costs per year)

Environmental monitoring of operations and permitting (1 percent of operation and maintenance costs per year)

These further cost items, if taken into consideration, may therefore add approximately 30% or more to the costs quoted in this document. Furthermore, no contingency costs, which would normally be about 15% to 20% of the quoted figures, have been included.

For the purpose of uniformity and to facilitate comparisons, the staff has used unit costs for earthwork operations which reflect contracted costs (Appendix K-4). However, many mill operators also are engaged in mining activities and thus possess the equipment and expertise to perform earthwork tasks. Hence, considerable savings, perhaps as much as 50% of the quoted figures, could be effected should the operator perform his own earthwork.

Also, it is important to note that, because it is not possible in this generic study to do the kind of optimization of operations and costs that experience has shown can be and is done in real cases, the estimates of total costs in this document are considered to be conservatively on the high side. For instance, by planning operations to avoid expensive unit cost operations (see for example, Appendix K-6, Section 1.2) or to avoid second handling, operators have, in fact, achieved lower costs than those assumed in this document.

Costs given in this document are of the engineering type, estimated to be accurate within about ±25%. In arriving at the cost estimates used for the assessment, the staff has investigated cost information from various sources. Cost information developed during numerous mill licensing actions in the past, published cost indexes, special studies on costs developed in support of this document,[1,2] and information supplied through consultation with mill operators, engineering firms, and construction contractors, have all been utilized by the staff in developing the cost data. A range of costs was determined from these sources for each of the unit cost items included in the assessment, and average costs were used by the staff in making the assessment. In addition, the staff considered the possible variations in costs due to location. Costs were derived for each of six uranium mining regions: Colorado Plateau, Wyoming Basins, Coastal Plain, Colorado and Southern Rockies, Northern Rockies, and the Great Plains. Uniform cost items were then derived for the model mill based on weighted average costs; variation in costs from region to region are small.

References

1. Dames and Moore, "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transporting Systems in the Western United States," report prepared for Argonne National Laboratory, July 1977.

2. Stanley Consultants, "Costs of Alternative Mill Tailings Management Programs," report prepared for Argonne National Laboratory, (Update of Appendix K-4.) March 1980.

APPENDIX K-9. DISPOSAL OF EXISTING TAILINGS PILES

The staff has investigated in the previous sections of this appendix the costs for tailings disposal alternatives at new tailings sites. The costs for disposing of existing tailings at operating sites are discussed in this section.

Since differing amounts of tailings are currently being stored under various conditions at mill sites, and it would be impractical to address all existing piles, the staff has assumed a standard reference tailings pile in developing costs for permanent disposal. The amount of tailings at an existing site are assumed to be equivalent to that generated by the model mill established in this document. Although this quantity of tailings is less than that existing at many mills, the staff has assessed costs for tailings disposal, using unit costs as in Appendix K-4. Relative cost impacts for other amounts of tailings can, therefore, be estimated by considering costs for similar unit operations.

For tailings being stored at existing mills, the staff has developed costs for two cases of permanent disposal alternatives: (1) recontouring and stabilizing existing piles in place, where site conditions would permit this, and (2) moving tailings to a new suitable location (assumed to be 10 km away from the existing site) where a pit is excavated for disposal. Case 1 is illustrative of the least of what would be required to meet the requirements of regulations being implemented. Where existing site conditions are clearly unacceptable from the point of long-term stability, relocation will be necessary, and Case 2 applies.

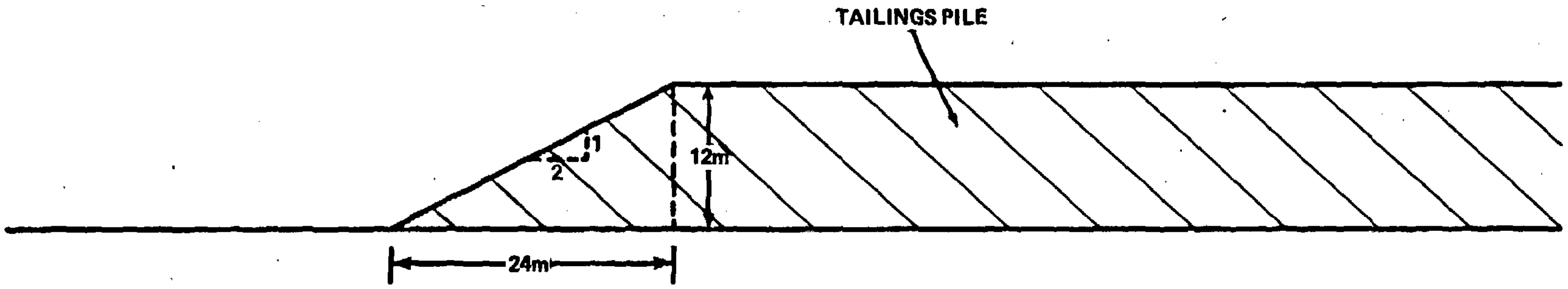
The original tailings pile is assumed to be bare, with a height of 12 m above grade and occupying an area of approximately 57 ha; the side slopes are taken to be 2 horizontal to 1 vertical. As with the base case, the embankments are assumed to be constructed with tailings, as has been practiced at some existing mills. Under Case 1, the tailings pile will be recontoured in place; the tailings will be moved from the sides so that the resulting final slope will be 8 horizontal to 1 vertical. Any excess tailings is redeposited on top of the pile. The entire tailings pile will then be covered with a 3 to 5 m-thick soil cover, and the side slopes will be covered with an additional 0.5 m-thick rock cover for stabilization (Figure K-9.1).

The volume of tailings moved in Case 1 will be approximately 4.1×10^5 m^3, and the total exposed area of the recontoured pile will be roughly 7.2×10^5 m^2 (the total area occupied by the recontoured pile would be roughly 62 ha). The staff has estimated costs for installing cover material at \$1.75/m^3 (App. K-4). Costs for moving tailings has been estimated to be \$0.70/m^3.[1] Costs for rock cover are estimated to be \$12/m^3 (App. K-4). Costs are, therefore, \$3 x 10^5 for recontouring, \$3.8 million for a 3 m cover, and \$1.9 million for rock cover. The total costs to move the tailings and provide a 3 m earthen cover, together with a 0.5 m rock cover over the side slopes, will therefore be \$6 million. If a 5 m-thick earthen cover is provided, total costs can be as high as \$8 million. If the top of the tailings pile is covered with a rock cover (0.15 m-thick), at \$12/m^3, the cost of stabilization would increase by about \$8 x 10^5. The total cost for recontouring and stabilization would, therefore, range between \$6 million and \$9 million under Case 1.

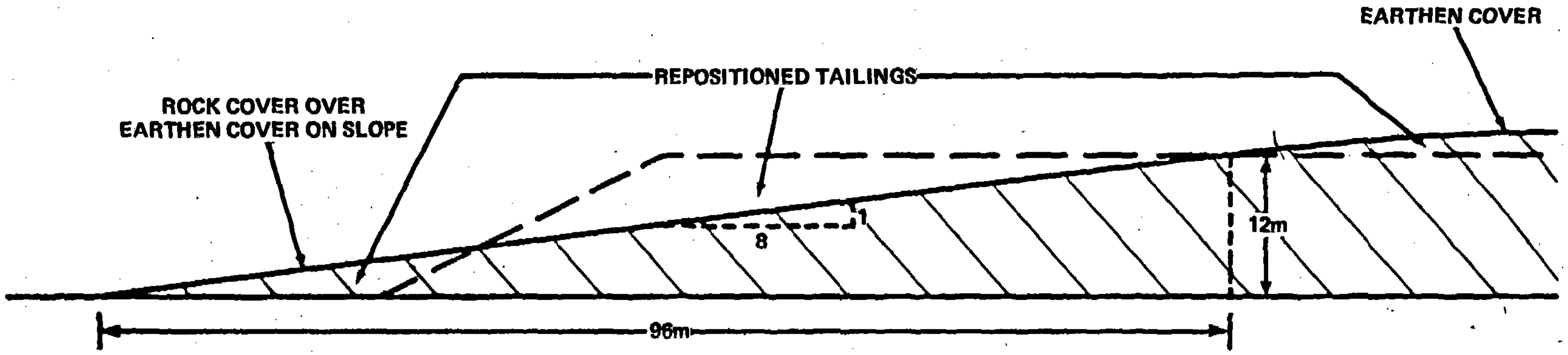
The above cost considerations have been made with the assumption that all cover materials may be obtained from onsite areas. If rock cover material is not available onsite, then hauling rock from offsite sources would be necessary. To illustrate the cost impact of doing this, the staff has estimated that the costs for installing rock cover, including hauling from an offsite source, would be done at a cost of about \$20/m^3 (App. K-4). Similarly, if earthen material must be hauled in from an offsite borrow pit, transportation costs can increase earthen cover installation costs significantly. To illustrate the cost impact of doing this, the staff has assumed a haul distance of 3.6 km (approximately 2 miles) in the case where earth must be obtained from an offsite source. With a transportation unit cost of \$0.27/m^3-km (App. K-4), the transportation costs for moving earth to the site would be roughly \$0.97/m^3. The cost for installing earthen cover in this case would therefore be about \$2.72/m^3.

In assessing the overall cover costs, however, the stafff considers that hauling to the site both of rock and earth would be unlikely; it is reasonable to expect that either rock or earthen material, if not both, would be available onsite. Hence, the staff has estimated varying total costs for Case 1 based on these considerations. If earthen material is available onsite, but rock cover material is hauled from an offsite source, total costs for Case 1 can vary between \$8 million, for a 3 m-thick earthen cover and rock cover over the slopes of the tailings pile only, and \$13 million, for a 5 m-thick earthen cover with rock cover over both the top and the slopes of the tailings pile. If earthen material is not available onsite but rock cover material is, total costs for Case 1 can vary between \$7 million and \$11 million, for similar cover variations as above. The entire range of costs, therefore, for Case 1, is from about \$6 million to \$13 million.

Where recontouring, covering, and hardening of the tailings impoundment in place assumed for Case 1 will not assure stability, then relocation will be necessary, and Case 2 applies. This



A. ORIGINAL CONFIGURATION



B. RECONTOURED PILE

Figure K-9.1 Recontouring and Stabilization of Existing Tailings Pile.

situation might arise where tailings are located in the path of a major drainage, or are situated where earthquake would most likely cause major disruption of the tailings pile. Under Case 2, the tailings are assumed to be totally removed, and roughly 1 m of soil beneath the tailings pile are assumed to be contaminated and, therefore, need to be removed together with the tailings as a part of site decontamination. The removed tailings and soil are assumed to be disposed into an excavated pit 80 ha in area located 10 km from the original site. The pit is assumed to be situated in a natural basin formed of a low permeability rock, so that the basin itself provides part of the containment necessary to hold the tailings (similar to Alternative 6 of App. K-4). A low-lying dam will be constructed on the lower side of the basin to provide the retaining structure. The material excavated from the pit is used partly as dam material and partly as final covering over the tailings.

It is assumed that sufficient material will be excavated to provide a minimum of 4 m cover and material for the low-lying dam. However, the amount of material used for dam construction is insignificant, compared with the volume used for cover material, so that material and construction costs for the dam would be negligible in this case. Hence, it is assumed that 4 m of earth will be excavated from the 80 ha basin area, and that 4 m of cover will therefore be provided. The tailings deposited into the 80 ha pit will thus be approximately 8 m thick, and will be situated partly above grade. The dam would be contoured to an outside slope of 8 horizontal to 1 vertical, and the slope of the dam would be stabilized with a 0.5 m-thick rock cover.

In assessing the costs for transporting the tailings from the original site to the disposal pit, the staff has assumed that 20% of the tailings to be transported exist as slimes, and 80% exist as sands. It would be necessary, therefore, to transport the 20% slimes portion of the tailings by truck, while the remaining 80% sands portion could be moved less expensively, via pipeline, as a slurry. Since the tailings sands would be relatively dry (with an assumed moisture content of about 10% by weight), it would be necessary to reslurry the sands before they can be pumped through the pipelines. The staff has assumed that the tailings sands would be removed from the existing pile, deposited into a holding tank, reslurried to approximately 50% water by weight, and then pumped to the disposal site. The slimes and contaminated soil would be removed, loaded into trucks and transported to the pit for disposal. The staff has assumed the standard tailings pile as described above would need to be moved.

Based on the above assumptions, then, roughly 1.3 x 10^6 m^3 of tailings slimes and about 6 x 10^5 m^3 of contaminated earth would be removed. The staff has estimated unit costs of tailings removal at $0.70/$m^3$,[1] for a removal cost of $1.3 million. Unit costs for transportation are as in Appendix K-4, at $0.27/$m^3$-km, for a transportation cost of $5 million. The staff considers the deposition costs of slimes and soil at the pit to be negligible. Total costs for moving the slimes and contaminated soil would therefore be about $6.3 million.

The tailings sands would have a volume of about 5.1 x 10^6 m^3. Removal costs, with unit costs as indicated above, $0.70/$m^3$, for sands would therefore be about $3.6-million. Capital costs for a 10 km-long, 18 cm-diameter pipeline is estimated at about $7.0 x 10^5 (from App. K-5; a scaling factor of $X^{0.6}$ has been used). Operating costs for pumping the slurry has been estimated at $0.022/MT-km (App. K-5). The volume of tailings sands estimated above by the staff would be equivalent to about 8.2 x 10^6 MT. Since roughly 40% more water by weight would be added to the sands during the reslurry process, the resulting weight of tailings slurry to be pumped would be about 11.5 x 10^6 MT. Operating costs would therefore be about $2.5 million. The staff has considered that costs for equipment and water for reslurrying are insignificant and has therefore not included these costs. Total costs for moving the tailings sands would therefore be about $6.8 million.

The disposal basin would be prepared by first stripping 0.6 m of topsoil from an area of about 80 ha; a 4 m-deep pit would then be excavated from the prepared basin. Excavation costs are estimated (App. K-4) at $1.20/$m^3$. Costs for stripping topsoil are therefore about $6 x 10^5, and costs for excavation of the pit would be about $3.9 million. No liners would be required since the pit is in low permeability rock. Costs for preparation of the basin would therefore be about $4.5 million.

Once the tailings have been deposited, the 80 ha area would be covered with about 4 m of backfilled overburden. Backfilling unit costs are estimated at $0.70/$m^3$;[1] the cost for covering would therefore be about $2.3 million. Reclamation of the top of the covered pile, at $5000/ha (App. K-4), would cost about $4 x 10^5. Providing a 0.5 m-thick rock cover, at $12/$m^3$ (App. K-4), over the recontoured slope would cost about $2 x 10^5. Total costs for reclamation and stabilization would therefore be about $2.9 million.

Combining the above items, the total cost under Case 2, for relocating tailings to a new suitable location, would be about $20.5 million. This cost has been assessed for excavation of a 4 m-deep pit and providing a 4 m-thick cover. If a 6 m-deep pit were excavated and a 6 m-thick cover were used, with the other factors held constant, the total cost would increase to about $23.5 million. If a 0.15 m-thick rock cover, at $12/$m^3$, is applied to the top of the tailings impoundment, stabilization costs would increase by about $1.1 million. Under Case 2, then, total costs would range between $20 million and $25 million.

Reference

1. R. S. Means Co., Inc., "Building Construction Cost Data 1979," Duxbury, MA, 1978.

APPENDIX L. RANKINGS OF TAILINGS MANAGEMENT ALTERNATIVES

A detailed analysis of the environmental impacts of nine alternative methods of tailings disposal has been carried out (Sec. 9.3), and these impacts have been compared with those resulting from the tailings disposal method utilized at the model mill (Sec. 6.2). In an attempt to provide some integration of the separate evaluations of potential impacts (e.g., on soils, water quality, radiological, etc.), a relative rating [from 1 (worst) to 10 (best)] of the various alternatives with respect to the environmental impact considered (Table L.1) was performed. As might be expected, the relative merits of the alternatives varied with the viewpoint adopted.

This rating system is greatly limited from several points of view, and for this reason is not intended for use in a benefit-cost evaluation such as that presented in Chapter 12. Its chief drawback is that it is limited to the alternatives considered in this document. There are a large number of potential site-specific tailings disposal programs with merits of their own that could not be considered. The final rating for the base case and alternatives are valid for intercomparison of these schemes when all are considered to be implemented within the model site under the conditions stipulated; they are not necessarily valid for other circumstances where other considerations may come into play. In real cases, it is expected that serious considerations would be given to a broad range of alternatives which meet criteria proposed in Chapter 12. The alternatives evaluated by the staff may be used as a starting point in such an investigation, but other reasonable alternatives may well be considered, and the preferred alternative may embody features not contemplated in this document.

Another limitation is the subjectivity involved. It is recognized that not all environmental components are equally important. An attempt was made to adjust for this circumstance by assigning weighting factors to the various components considered. The final factors, listed in Table L.2, are the average of those assigned by the staff members who ranked the alternatives; they thus represent a "consensus."

Table L.1. Initial Ranking of Alternatives

Environmental Regime	Base Case	Alternative								
		I	II	III	IV	V	VI	VII	VIII	IX
Air quality	1	3	6	6	6	7	5	10	10	5
Land use	1	2	8	8	4	4	3	10	9	3
Mineral resources	10	9	8	8	8	7	9	6	1	9
Surface water	1	2	6	6	7	10	4	6	8	3
Groundwater	1	2	4	6	8	5	4	9	10	3
Soils	1	2	8	9	8	2	2	9	10	2
Terrestrial biota	1	2	7	6	8	2	2	9	10	2
Aquatic biota	1	2	5	6	5	5	3	8	10	3
Community	1	2	5	6	6	8	4	7	10	4
Radiological	1	3	8	8	8	8	8	9	10	8
Stability	1	3	8	8	8	8	8	9	10	6

Table L.2. Weighted Ranking of Alternatives

Environmental Regime	Wt. Factor	Base Case	Alternative								
			I	II	III	IV	V	VI	VII	VIII	IX
Air quality	0.4	0.4	1.2	2.4	2.4	2.4	2.8	2.0	4.0	4.0	2.0
Land use	0.5	0.5	1.0	4.0	4.0	2.0	2.0	1.5	5.0	4.5	1.5
Mineral resources	0.1	1.0	0.9	0.8	0.8	0.8	0.7	0.9	0.6	0.1	0.9
Surface water	0.4	0.4	0.8	2.4	2.4	2.8	4.0	1.6	2.4	3.2	1.2
Groundwater	0.6	0.6	1.2	2.4	3.6	4.8	3.0	2.4	5.4	6.0	1.8
Soils	0.4	0.4	0.8	3.2	3.6	3.2	0.8	0.8	3.6	4.0	0.8
Terrestrial biota	0.3	0.3	0.6	2.1	1.8	2.4	0.6	0.6	2.7	3.0	0.6
Aquatic biota	0.3	0.3	0.6	1.5	1.8	1.5	1.5	0.9	2.4	3.0	0.9
Community	0.5	0.5	1.0	2.5	3.0	3.0	4.0	2.0	3.5	5.0	2.0
Radiological	1.0	1.0	3.0	8.0	8.0	8.0	8.0	8.0	9.0	10.0	8.0
Stability	0.8	0.8	2.4	6.4	6.4	6.4	6.4	6.4	7.2	8.0	4.8
Total		6.2	13.5	35.7	39.6	37.3	33.8	27.1	45.8	54.8	24.5

APPENDIX M. REGIONAL POTENTIALS FOR SURFACE WATER CONTAMINATION FROM AN UNLINED TAILINGS POND

The western United States contains many different kinds of ecosystems, ranging from the Texas Coastal Plains through the high, cold deserts of the Colorado Plateau to the high-altitude forests of the Northern Rocky Mountains. The aquatic habitats are also vastly different, with warm turbid coastal-plain rivers, intermittent streams, and cold-water rivers. The U.S. Environmental Protection Agency and other agencies have established water quality criteria for various water uses (Table M.1). Because of the regional variability of the water quality of western U.S. surface waters, a generic treatment of water use constraints is not feasible; therefore, water quality problems related to seepage from uranium tailings are examined for representative rivers in the six regions. The rivers selected are: Pend Oreille River in the Northern Rocky Mountains, the Cheyenne River in the Western Great Plains, the Wind-Bighorn River in the Wyoming Basin, the Arkansas River in the Southern Rocky Mountains, the Dolores-San Miguel River and Rio San Jose in the Colorado Plateau, and the Nueces River in the Texas Coastal Plains. Each of the rivers and regions is characterized in the Supplement.

Table M.1. Selected Water Quality Criteria for Water Use Categories

	Domestic (drinking water quality)		Irrigation	Industrial	Stock Watering	Biological
Element[a]	Recommended Limit[b]	Maximum Permissible Limit[c]	Recommended Limit[b]	Recommended Limit[b]	Recommended Limit[b]	Recommended Limit[b]
Cd	10.0	10.0	-	-	-	12.0
Cu	1000.0	-	100.0	-	-	20.0
Fe	300.0	-	-	100.0	-	1000.0
Pb	50.0	50.0	-	-	-	100.0
Mn	50.0	-	500.0	-	10,000.0	1000.0
Hg	2.0	2.0	-	-	-	0.05
Se	10.0	10.0	-	-	-	20.0
Zn	5000.0	-	-	-	-	1000.0
F	1000.0	1400.0	10,000.0	1000.0	1,000.0	1500.0
SO_4	5.0×10^5	2.5×10^5	2.0×10^5	-	5.0×10^5	5.0×10^5

[a] Concentrations given in μg/L.

[b] Concentration given as threshold concentrations for specific use or water quality criterion designated to protect biotic communities or prescribed water use or quality with an adequate degree of safety. Domestic water quality criteria according to: "Quality Criteria for Water," U. S. Environmental Protection Agency EPA 440/9-76-023, 501 p., 1976; J. E. McKee and H. W. Wolf, "Water Quality Criteria," 2nd ed., California State Water Res. Control Board Publ. 3A, 548 p., 1971.

[c] Water quality standards according to: (USPHS-USEPA), U. S. Public Health Service Publication 956, 1962; U. S. Environmental Protection Agency, 40 CFR 400-41 FR 21191, 1976.

The calculations are based upon the assumption that an unlined tailings pond is located adjacent to a river and that at some point in time the concentrations of contaminants reaching the river will be similar to the concentrations in the mill effluent. Both of these assumptions are conservative, and calculations based upon them yield an upper bound for the effects. Observed effects in real cases are expected to be less than those calculated, but realistic estimates are difficult to make because of uncertainties in permeabilities, absorptive capacities, etc. As a result of these uncertainties, there is no simple relationship between effects produced by given initial concentrations. Only those water quality parameters (Table M.1) with potential for enrichment from tailings pond seepage are considered here. Average annual concentrations of the selected materials in the representative rivers are given in Table M.2. In some instances, existing concentrations exceed recommended criteria (e.g., Se and Hg in the Pend Oreille River, SO_4 in the Cheyenne River, Hg and SO_4 in the Wind-Big Horn River).

The postulated chemical composition of seepage (model mill) is given in Table M.3; however, concentrations will vary depending on the chemical composition of the ore and the nature of the milling processes to which it is subjected.

The minimum river flows (m^3/s) needed to meet the selected water use criteria (Table M.1) were calculated by fhe following equations:

$$X = \frac{C_p - C_c}{C_c - C_a} \qquad (1)$$

$$M_f = X \cdot S_r \qquad (2)$$

where: X = Dilution factor

C_p = Mill tailings seepage concentration (μg/L)

C_c = Recommended water quality criteria (μg/L)

C_a = Average ambient river concentration (μg/L)

S_r = Seepage rate from tailings pond (m^3/s)

M_f = Minimum required river flow (m^3/s)

The calculations are based on the conservative (worst case) assumption that the undiluted, chemically unchanged seepage from the tailings disposal area will eventually reach an adjacent river. The seepage rate is calculated in Appendix E-1 for an unlined tailings pond. The values presented below are a very conservative case for an unlined tailings pond. In addition, it is assumed that complete mixing will eventually be achieved downstream of the ingress of contamination

The minimum river flow for dilution of each "contaminant" listed in Table M.2 was calculated by use of Equations 1 and 2 and is given in Table M.4. These calculated flows were compared with the range of recorded river flows given in the Supplement and evaluated relative to regional water use constraints. This evaluation indicated that within the group of representative rivers, all categories of use may be affected. For the conservative case considered, representative interpretations of data given in Table M.4 are:

1. In the Pend Oreille River domestic use presents the major constraint. Minimum river flows of 130 m^3/s (4640 cfs) must be maintained to ensure adequate dilution, and thus acceptable concentrations, of manganese for domestic use.
2. In the Cheyenne, Dolores, and San Miguel Rivers, biological criteria for the protection of aquatic life are limiting constraints. The average flows of these rivers [2 to 2.3 m^3/s (70 to 80 cfs)] are not sufficient for dilution of copper contamination from seepage.
3. In rivers such as the Cheyenne, Rio San Jose, and Arkansas, where periods of no flow have been recorded, water quality problems are apparent for all criteria categories.

This demonstration of regional variability was made to emphasize that although generic impacts can be identified, it is necessary to consider each site individually when assessing the magnitude of a potential impact. From the results of the conservative calculations, certain problem areas that merit further consideration can be identified.

Table M.2. Selected Water Quality Parameters in Representative Rivers of the Western United States Uranium Milling Regions

	Northern Rocky Mountains			Western Great Plains			Wyoming Basin	
Concentrations of Dissolved Chemicals[a]	Pend Orielle Lake	Pend Orielle R. (mainstem)	Pend Orielle R. (tributaries)	Cheyenne R. (mainstem)	Cheyenne (tributaries)	Angostura Reservoir	Wind-Bighorn R. (mainstem)	Wind-Bighorn R. (tributaries)
Hg		2.5 (5.1)[a]	0.4	0.1			5.9	
Cd	5.6 (35.9)	4.8 (6.3)	1.6	1.2 (1.6)			0.2	
Cu	8.0	5.4 (15.3)	3.0	9.9 (25.5)	3.3 (8.9)		3.5	83.0 (150.0)
Fe		11.7		771.6 (2198.0)	191.9 (1440.0)		70.3	
Pb		59.4 (97.0)		36.0 (88.5)	43.3 (108.0)		3.4	
Mn		23.5		172.3 (594.0)	202.4 (620.0)		9.0	100.0
Zn	14.8 (24.7)	1.7	17.3	50.5	58.7 (108.2)		24.5 (25.0)	14.0
Se		41.0		17.7 (71.6)				
SO_4 (mg/L)		5.7		1006.2 (2040.4)	280.1 (1522.2)	800.0	148.9 (321.3)	308.6 (2452.4)
F		407.0 (875.0)		670			384	
Al			202.0	298.3 (740.0)				
V								

Table M.2. Continued

Concentrations of Dissolved Chemicals[a]	Southern Rocky Mountains		Colorado Plateau				Texas Coastal Plains		
	Arkansas R. (mainstem)	Arkansas R. (tributaries)	Dolores & San Miguel R.	Rio San Jose R. (mainstem)	Rio San Jose R. (tributaries)	Colorado R.	Nueces R. (mainstem)	Nueces R. (tributaries)	Lake Corpus Christi
Hg	0.03	0.1 (0.7)					0.2 (0.3)		
Cd			3.5 (8.2)		5.0		0.3		
Cu		7.8 (72.7)	19.7 (43.5)				15.6 (30.2)		
Fe	26.3		514.2 (1,552.5)	10.0			52.4		
Pb	2.0		33.8 (65.5)	40.0	70.0		1.0		
Mn	126.0 (325.0)	101.7 (440.0)	169.6 (302.7)	100.0	100.0		15.9 (40.0)	89.6 (101.0)	
Zn		27.7 (60.0)	42.3 (83.2)	85.0 (110.0)	180.0		18.9		
Se	4.1		2.8				0.8		
SO_4 (mg/L)	615.6 (1324.8)	517.5 (1840.0)	168.6 (434.9)	61.8 (84.0)	41.6 (81.0)	39.0	43.1 (150.5)	48.8 (143.4)	53.7
F	910		400.0	370.0 (380.0)	207.8		260		
Al			100.0						
V			8,256.0 (65,600.0)						

[a] Values given are average concentrations, expressed in μg/L except as noted. (Numbers in parentheses are maximum recorded concentration.)

Table M.3. Composition of Tailings Pond Seepage

Parameter	Concentration, μg/L
pH	2
Aluminum	0.0
Ammonia	5×10^5
Arsenic	200
Calcium	5×10^5
Carbonate	---
Cadmium	200
Chloride	3×10^5
Copper	5×10^4
Fluoride	5000
Iron	1×10^6
Lead	700
Manganese	5×10^5
Mercury	7.0
Molybdenum	1×10^5
Selenium	2×10^4
Sodium	2×10^5
Sulfate	3×10^7
Vanadium	100
Zinc	8×10^4
Total dissolved solids	3.5×10^7

Table M.4. Flow (m^3/s) Required in Representative Western Rivers to Dilute Seepage Contamination from an Unlined Tailings Pond to Meet Water Quality Criteria for Various Uses

	Pend Oreille River[a]						Cheyenne River[a]					
	A[b]	B	C	D	E	F	A	B	C	D	E	F
Cd	0.18	0.25	0.25	-	-	-	0.12	0.15	0.15	-	-	-
Cu	23.85	0.34	-	3.68	-	-	34.55	0.35	-	3.85	-	-
Fe	7.05	24.20	-	-	79.01	-	30.59	-	-	-	(-10.37)	-
Pb	1.16	(-5.15)[c]	(-5.15)[c]	-	-	-	0.75	3.43	3.43	-	-	-
Mn	3.57	131.41	-	7.31	-	(-3.48)[c]	4.19	(-28.60)	-	0.11	-	(-3.48)
Hg	(-0.20)[c]	(-0.95)	(-0.95)	-	-	-	(-9.74)	0.24	0.24	-	-	-
Se	(-6.63)	(-4.50)	(-4.50)	-	-	-	60.61	(-18.10)	(-18.10)	-	-	-
Zn	0.55	0.11	-	-	-	-	0.58	0.11	-	-	-	-
F	0.02	0.03	0.41	(-0.01)[c]	0.03	0.03	0.03	0.08	0.03	(-0.01)	0.01	0.08
SO_4	0.41	0.41	0.83	1.04	-	0.41	(-0.41)	(-0.41)	(-0.28)	(-0.26)	-	(-0.41)

	Wind-Bighorn River[a]						Arkansas River[a]					
	A	B	C	D	E	F	A	B	C	D	E	F
Cd	0.11	0.14	0.14	-	-	-	-	-	-	-	-	-
Cu	21.10	0.34	-	3.60	-	-	-	-	-	-	-	-
Fe	7.48	30.30	-	-	234.49	-	7.14	25.46	-	-	94.59	-
Pb	0.50	1.04	1.04	-	-	-	0.49	1.01	1.01	-	-	-
Mn	3.51	84.96	-	7.08	-	(-3.48)	3.90	(-45.88)	-	9.32	-	(-3.48)
Hg	(-0.08)	(-0.12)	(-0.12)	-	-	-	24.36	0.24	0.24	-	-	-
Se	-	-	-	-	-	-	8.75	23.59	23.59	-	-	-
Zn	0.56	0.11	-	-	-	-	-	-	-	-	-	-
F	0.02	0.05	0.02	(-0.01)	0.05	0.05	0.04	0.31	0.01	(-0.01)	0.31	0.31
SO_4	(-0.21)	(-0.21)	(-0.17)	(-0.17)	-	(-0.21)	(-1.77)	(-1.77)	(-0.57)	(-0.50)	-	(-1.77)

Table M.4. Continued

	Dolores and San Miguel Rivers[a]						Rio San Jose[a]					
	A	B	C	D	E	F	A	B	C	D	E	F
Cd	0.15	0.20	0.20	-	-	-	-	-	-	-	-	-
Cu	1161.12	0.35	-	4.33	-	-	-	-	-	-	-	-
Fe	14.23	(-32.57)	-	-	(-16.82)	-	7.02	24.02	-	-	77.32	-
Pb	0.73	3.00	3.00	-	-	-	8.01	4.84	4.84	-	-	-
Mn	4.19	(-29.17)	-	10.54	-	(-3.48)	3.85	(-69.67)	-	8.69	-	(-3.48)
Hg	-	-	-	-	-	-	-	-	-	-	-	-
Se	8.10	19.34	19.34	-	-	-	-	-	-	-	-	-
Zn	0.58	0.11	-	-	-	-	0.60	0.02	-	-	-	-
F	0.00			(-0.01)	<0.01	<0.01	<0.01	<0.01	<0.01	-0.01	<0.01	<0.01
SO_4	0.62	0.62	2.54	6.60	-	0.62	0.47	0.47	1.10	1.50	-	0.47

	Nueces River[a]					
	A	B	C	D	E	F
Cd	0.11	0.14	0.14	-	-	-
Cu	79.01	0.35	-	4.01	-	-
Fe	7.33	28.13	-	-	146.41	-
Pb	0.48	0.99	0.99	-	-	
Mn	3.54	102.23	-	7.19	-	(-3.48)
Hg	(-3.26)	0.26	0.26	-	-	-
Se	7.25	15.15	15.15	-	-	-
Zn	0.56	0.10	-	-	-	-
F	0.02	0.04	0.02	(-0.01)	0.04	0.04
SO_4	0.45	0.45	1.00	1.32	-	0.45

[a] The annual average discharge (AAD) and minimum recorded discharge (MRD) for these rivers are as follows:
Pend Oreille: AAD = 820 m^3/s; MRD = 3.09 m^3/s
Wind-Bighorn: AAD = 100 m^3/s; MRD = 1.39 m^3/s
Rio San Jose: AAD = 1.39 m^3/s; MRD = 0
Dolores and San Miguel: AAD = 2.01 m^3/s; MRD = 0.96 m^3s.
Cheyenne: AAD = 2.21 m^3/s; MRD = 0
Arkansas: AAD = 5.89 m^3/s; MRD = 0
Nueces: AAD = 2.49 m^3/s; MRD = 0.20 m^3/s

[b] Use categories:
A - Biological
B - Domestic
C - Domestic Maximum Permissible
D - Irrigation
E - Industrial
F - Stock Watering.

[c] Negative numbers in parentheses indicate that average ambient river concentration already exceeds criterion.

APPENDIX N. RECLAMATION OF URANIUM MILL AND TAILINGS DISPOSAL SITES

1. INTRODUCTION

The ultimate objectives for any uranium mill tailings management scheme are (a) to prevent the introduction of potentially hazardous material into the biosphere (stabilization), and (b) to return decommissioned land areas to productivity (reclamation). Achievement of one objective does not necessarily imply the achievement of the other; any tailings management plan should therefore provide for both stabilization and reclamation. Methods of tailings disposal, including measures to stabilize tailings, are evaluated in Chapters 8 and 9 and Appendix B; reclamation is discussed herein. The discussion is focused on reclamation of the surface of the tailings cover; it is postualed that methods that can be used sucessfully to reclaim this surface will be effective in other areas of the mill site.

For purposes of this discussion of reclamation it is assumed that the tailings disposal scheme is adequate to prevent seepage and to reduce radioactive emissions to acceptable levels. It is also assumed here that "reclamation" of tailings disposal sites implies a return of the land to primary production (i.e., vegetation), although alternative land uses (e.g., parking lots, recreational facilities) are conceivable. Generally speaking, the State is the smallest governmental until that can reasonably be expected to regulate land reclamation. As is evident from Table N.1, regulations pertaining to reclamation vary among states.

The success of any reclamation scheme whose objective is to return the area to primary production will depend mainly on the properties of the earth cover and on natural precipitation. Any general discussion, as for a generic statement such as this, will lack the details pertaining to site-specific conditions that would be essential for discussion of reclamation at a real site; however, major problems unique to the individual uranium resource regions are discussed where appropriate. This discussion on reclamation is presented for completeness. As discussed in Section 9.4.1, it is unlikely vegetation can be counted upon to provide effective continuing erosion control in many arid and semiarid milling regions, and, as a consequence, rock covering may be required to stabilize the tailings cover.

2. MAJOR FACTORS IN THE DESIGN OF A URANIUM MILL TAILINGS RECLAMATION PLAN

The major factors that must be considered in designing a reclamation plan for uranium mill tailings are (a) the desired land use, (b) climate of the site or region, (c) materials available as cover and growth substrate, (d) backfilling and grading procedures, (e) revegetation procedures, (f) maintenance procedures, and (g) total cost. For purposes of this document, it is assumed that the desired land use is primary production i.e., vegetation, and that the cost of any reasonable plan is acceptable. The remaining factors are discussed below.

2.1. Climate

Theoretically, it is possible to grow almost any type of vegetation in any region--e.g., if gaint growth chambers with controlled temperature, light, and water were constructed over the tailings disposal site and an ideal growth medium provided. This, however, is not considered to be a "reasonable" reclamation program. A reasonable program would be one based on the climatic conditions extant in the given region. Selection of seed species to be planted should have, as an objective, the eventual self-maintenance of ground cover in the absence of any supplemental irrigation or man-made heat sources. Species adapted to the natural water regime are essential, because in most of the uranium resource regions available water is most often the limiting factor for plant growth. Species of vegetation adapted to intermountain plant communities, which in turn are adapted to the corresponding climate and soils, are listed in Table 31.1 of Reference 1.

2.2 Earth Cover Materials

Aside from climate, the critical factor in reclamation is the soil or other earth material used as substrate for plant growth. It is often assumed that storing "topsoil" and eventual layering of the stored material over "overburden" or other "mine spoils" ensures successful revegetation with good forage species. This may not necessarily be true if the soil is high in salt content (saline) and/or sodium (alkali), as is sometimes the case in arid and semiarid regions. Leaching of such soils with nonbrackish water or revegetation with salt-tolerant species are two alternative treatments in such cases.

Table N.1. Reclamation Regulations in Some States of the Uranium Resource Regions[a]

State	Permitting Agency	Reclamation Bond		Reclamation of Exploration Disturbance	Overburden Analysis	Topsoil		Highwall Limitation (feet)	Grading		Topsoil Depth (feet)	Vegetation Establishment		Covering of Acid Forming or Toxic Materials	Completion of Reclamation Required
		Amount	Release Time			Stockpiling	Erosion Control		Contour %	Time Limitation (months)		Seeding Time After Grading (days)	Success Evaluation % Cover		
Arizona	Coal mines on Indian lands, therefore, subject to USGS regulations														
Colorado	Land Reclamation Board	$50 plus $15 for each acre to be affected	10 years						Grade Ridges and peaks to width of 15 feet at top. Commensurate with proposed land use	Within 3 years	2 feet over acid forming or toxic materials		Tree spacing 10 by 10 feet	Cover to depth which will protect drainage system from pollution if covered with water must be no less than 4 feet	Within 3 years
Montana	Department of State Lands	Not less than $200 nor more than $2,500 per acre with $2,000 minimum	Partial release upon approval of department, remaining bond will not be released prior to 5 years from initial planting	As soon as possible	Soil and overburden analysis	Removal and stockpiling to precede each step of mining operation. Topsoil removal required for prospecting activities	May require immediate planting of annual and/or perennial crop	No greater than 20 degrees from horizontal	Approximate original contour no final graded slopes to exceed 5 horizontal to 1 vertical (5:1)	Within 90 days after department has determined the operation is complete	Approximate original	First appropriate season following completion of grading and topsoiling	Permanent diverse vegetation cover	May require burial with up to 8 feet of material	
New Mexico	Coal Surface Mining Commission	Commission may require operator to file bond in an amount sufficient to ensure compliance	Upon satisfaction of Commission		Soil analyses				Grading to produce a gently undulating topography or consistent with proposed land use	Shall be completed within a reasonable and prescribed time limit		Shall be completed within a reasonable and prescribed time limit	Dependent upon proposed land use	Depth determined in approved mining plan	
North Dakota	Public Service Commission	$1,500 for each acre affected	5 years after termination of permit, may be extended, partial release may be effected upon completion of certain tasks		pH sodium adsorption ratio electrical conductivity texture (by feel)	Up to maximum of 5 feet must be suitable for plant growth: other material may be used if suitable for plant growth		Back sloped to angle not to exceed 35% from horizontal	Approximate original contour unless specified by commission		2 feet				Prior to 3 years after termination of permit term
Oregon	Department of Geology and Mineral Industries	Not to exceed $300/acre to be surface mined	After inspection and approval of Department					Ensure safety of public	Prepare permit area in best practical manner for planned subsequent beneficial use	As promptly as possible			Vegetation survival of 75%, uniformly distributed, for one growing season		Within not more than 3 years after completion of work
Texas	Railroad Commission of Texas	Determined by Commission to be of sufficient amount to ensure reclamation plan completed	Liability shall be for the duration of operations and reclamation and for a period coincident with the operators responsibility			Required or best available subsoil	Cover with quick growing plants		Approximate original contour	Proceed as contemporaneously as practicable	Replace topsoil or best available subsoil		Diverse vegetative cover native to the affected land when vegetation existed prior to mining	Must be treated or disposed in a manner designed to prevent contamination of ground or surface waters	5 years
Utah	Division of Oil, Gas, and Mining	Determined by Division	Liability shall continue until released by division		pH	Required unless no such material exists, must provide explanation			To be developed as part of reclamation plan			Not required if there is no original cover. Must provide alternate procedure to minimize or control erosion or siltation. Time table required in reclamation plan		Must provide explanation of how such materials will be segregated and disposed of in reclamation plan	Return land concurrently with mining or within a reasonable time therafter to a stable ecological condition compatible with past, present and probable future land uses
Washington	Department of Natural Resources	Not less than $100 nor more than $1,000 per acre	Approval of Director						Peaks and depressions of spoil banks graded to gently rolling topography excavations side slopes shall be no steeper than 1½ feet horizontal to 1 foot vertical	In accordance with plan	Shall be made with non-noxious, nonflammable, noncombustible solids			Covered with at least 2 feet of clean fill	Revegetation shall be accomplished within 2 years after completion or abandonment of surface mining on each segment of the permit area
Wyoming	Division of Land Quality	Amount equal to estimated cost of reclaiming affected land in no event will bond be less than $10,000	75% may be released when reclamation plan complete for affected land Remaining portion shall not be less than $10,000 and shall be held for at least 5 years after date of reduction to assure proper revegetation	Must meet with approval of administrator		Topsoil unless non-existent, then must stockpile	Protect from wind and water erosion and from acid or toxic materials		Approximate original contour	Conduct according to approved mining plan	Required	According to approved reclamation plan	Cover of native vegetation capable of self-regeneration	Cover, bury or impound	Reclaim affected land as mining progresses in conformance with approved reclamation plan

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[a] Excerpted from: R. P. Hensen, "Statutory and Regulatory Aspects of Mined Land Reclamation," in: Reclamation of Western Surface Mined Lands, K. C. Vories, editor, Workshop Proc. March 1-3. ERT, Inc., pp. 1-7, 1976.

Soils of the arid and semiarid regions that do not have high concentrations of salt or alkali may nevertheless be of low fertility because of low organic matter content (less than 1%), low nitrogen and plant-available phosphorus, and, as in certain areas of Wyoming, Texas, and South Dakota, relatively high concentrations of selenium. Segregation and storage of soils appears to result in a decreased productivity, most likely because of disruption of soil structure which affects aeration and water relationships, changes in the ecology of the soil microflora and fauna, which in turn can be expected to affect soil fertility.[2] A soil is a nonhomogeneous, multilayered, dynamic medium for plant growth and has developed during hundreds of years of interactions among climate, parent material, topography, and vegetation. The act of removing the surface layers ("topsoil") destroys the integrity of the soil profile, and some would argue that such material is no longer a soil. "Topsoil" (a term that is not found in the vocabulary of soil science) as defined by mine operators, regulatory agencies, and other laymen, is variously the top 15 cm (6 inches), plowdepth, loose material easily removed by scrapers, or surface material capable of supporting plant growth. The definition is not critical for purposes of reclamation, but can lead to ambiguity and erroneous interpretation of laboratory and field test results that have been developed for agricultural soils.

Most of the soils in arid and semiarid regions are relatively shallow; it is expected, therefore, that stockpiled "topsoil" will be insufficient in quantity to provide adequate depth of cover above tailings impoundments. Since it is undesirable to obtain "topsoil" from borrow areas (which would simply result in creating another area of disturbance), it is expected that mine overburden and "spoil" will also be used as tailings cover and medium for plant growth. Such material has essentially no organic matter, poor structure, poor water-holding capacity, poor stability against erosion, poor aeration characteristics, and poor fertility in terms of nitrogen and plant-available phosphorus. In addition, the use of overburden that includes seleniferous shales, or that is high in molybdenum, boron, or vanadium, brings to the root zone material that can become toxic to plants or to herbivores. Chemical analysis of any material that is to be used as a medium for plant growth is imperative, not only to determine the types and quantities of fertilizer and amendments needed, but also to determine any concentrations of potentially toxic elements. Chemical analysis should include determinations both of total and plant-available constitutents; elements that are not initially available for plant uptake may slowly become available with time through chemical and microbiological reactions in the material.

Soils of more humid regions tend to be deep and are relatively high in organic matter and fertility. Water availability will not usually be the limiting factor in revegetation in these areas, but decreased fertility after "topsoil" storage, and disruption of soil structure, is expected. Runoff and concomitant erosion are critical to these areas. Soils in these regions tend to be acid, and toxicities due to some trace metals may become important if previously buried material is brought to the root zone.

Aside from adequate fertility, good soil structure is necessary for good plant growth because of the contribution of soil structure to the water regime, aeration, soil microfloral ecology, and resistance to wind and water erosion. Good soil structure can be developed only through the incorporation of organic matter in the presence of appropriate soil microorganisms that decompose organic material into large molecules that bind individual soil particles into stable aggregates. Man-made molecules (soil conditioners) that attempt to imitate the action of organic matter in soil have been developed; initially, soil conditioners can enhance soil structure, but the effects are not lasting and the conditioners are expensive for use in large areas such as on tailings disposal sites.

In summary, whatever be the term applied to the earth material used as a medium for plant growth over tailings, the material should:

1. Be of sufficient depth to provide anchor for indigenous plant species to reduce the likelihood that roots will penetrate to the tailings body;
2. Provide macro- and micronutrients;
3. Contain no toxic concentrations of elements such as Se, V, B, Mo, or As;
4. Have, if possible, a granular, water-stable aggregate structure. This condition will be the most difficult to meet over the short-term, since most overburden material can develop into such structure only over a long period of weathering with annual incorporation of organic matter. However, it is a goal that should be approached as closely as reasonably possible.

An approximate range of chemical and physical properties of earth material (soil, overburden, or spoil) that can serve as criteria for evaluating the plant growth suitability of the material is given in Table N.2.

Table N.2. Selected Physical and Chemical Criteria for Earth Material[a] as a Medium for Plant Growth on Uranium Mill Tailings Disposal Sites

Property[b]	Value or Concentration	
	Adequate	Poor
Texture	Wide Range	Rocks, coarse sands, heavy clays
Bulk density (g/cm^3)	0.8- 1.7	> 1.8
Available water capacity (%)	5 -30	< 5
Salinity (mmhos/cm)	< 4	> 8[c]
Exchangeable sodium (%)	<15	>15[c]
Organic matter (%)	1 - 4	< 1
Selenium (ppm)	0.1- 2	> 2[d]
Molybdenum (ppm)	< 1	Variable[e]
Boron (μg/mL in sat. extr.)	< 0.5	> 1[c]
pH	4 - 9[f]	< 4

[a] Earth material includes soil, overburden and spoil.

[b] The table includes only those properties that are considered by the staff to be critical to revegetation of mill tailings and which are difficult to alter. Properties such as content of macro- and micronutrients are not included, since these can be added to the growth medium as required under the specific revegetation conditions. Elements such as vanadium and arsenic, whose toxicities are highly dependent on their chemical state in the particular growth medium and on the plant species growing in that medium, are not included. Specification of "adequate" or "poor" concentration ranges for such elements would be meaningless. For these elements, each site must be evaluated according to its particular conditions. In general, soils have been found to contain up to 38 ppm As and 20-500 ppm V.

[c] Certain plant species can adapt to more extreme conditions.

[d] Certain plant species can adapt to higher concentrations of soil selenium but then may become toxic to herbivores.

[e] Toxicity to foraging animals will depend on pH and drainage characteristics.

[f] Adequacy depends on the plant species.

2.3 Backfilling and Grading Procedures

Experience with reclamation of land strip-mined for coal, although not always directly applicable to uranium mining and milling activities, indicates that the handling of overburden is critical to the degree of reclamation success. The method of overburden placement, handling, and final reclamation are influenced by regional characteristics, particularly topography and climate. The methods selected must take into account site-specific factors, land use, local, state, and Federal regulations, technical feasibility, and equipment capability, as well as cost limitations.

Whether the tailings are deposited above ground, below grade, or in the mine pit, the covered site should be contoured or terraced, not only to blend in with the natural landscape, but primarily to reduce the erosion hazard, which will tend to be severe on bare slopes. Contouring or terracing will be easier if the tailings are deposited below grade or in the mine pit, rather than above ground. The latter action will tend to result in an earthen mound, highly susceptible to erosion.

Grading should be carried out immediately after backfilling so as to prevent excessive compaction of the surface and to conserve moisture. A number of methods for surface treatment of reclaimed areas prior to seeding are in use including:[3]

1. Terracing--Terraces are constructed along the contours with a bulldozer and agricultural harrow. Requires precision in structuring and is often used with a series of small check dams and sediment ponds.
2. Furrow grading--A series of parallel furrows collect water and silt. As the ridges of the furrows weather, silt collects in the middle of the furrow and gradually fills it. This method has been successful on steep, erosive, and toxic spoils in eastern and midwestern states.
3. Gouging--Shallow depressions, about 35-40 cm (14-16 inches) wide, 15-20 cm (6-8 inches) deep, and 30-60 cm (1-2 ft) long, are scooped out. This method has been shown to effect surface water retention on gradual slopes and flat areas, and is used primarily in arid to semiarid climates.
4. Dozer basins--Elongated depressions, usually about 1 m (3 ft) deep and 8 m (25 ft) long, are constructed with an angled bulldozer blade. These basins trap and retain large amounts of surface runoff and have been effective in regions that experience high intensity storms.
5. Deep chiseling--Consists of series of parallel slots, 15-20 cm (6-8 inches) deep. Curtails erosion from low intensity storms and is highly suited for broadcast seeding of compacted spoils.

2.4 Revegetation

In most cases, seeding and revegetation of prepared earth material is best accomplished in two phases--initially with quick-growing grasses and legumes, followed in a year or two with perennial shrubs and low-growing woody species. The principal objective of the initial seeding is to establish a vegetative cover with proliferating root systems to reduce the hazard of erosion and to build up organic matter in the soil. During the first phase of the revegetation program, fertilizer, lime (if necessary), and clean mulches should be applied; at sites in arid regions it probably is necessary to supplement natural precipitation until root systems are established. It is essential that the area be fenced to prevent grazing by livestock during this period. Experience with the reclamation of coal mine spoils in the West and Southwest indicates that perhaps the single most important determinant of successful reclamation is restriction of grazing. Selection of the seed mixtures will depend on the availability of seed sources, in addition to the factors of climate and soil discussed above; site-specific recommendations can be obtained from the district Soil Conservation Service, state land quality offices, and experience at reclaimed coal lands in the same region.

In general, seeding should be carried out before the period of maximum rainfall. Seeding equipment is usually an end-wheel press drill or rangeland drill. On slopes where the use of such drills is not feasible, the seed can be broadcast and covered with earth by using a harrow or by dragging a heavy chain. Fertilizer can be applied at the time of seeding, or soon after, either wet or dry. If wet (hydroseeding), the seed-fertilizer-water mixture should not be stored, since the salt solution can damage seed coats.

It is usual practice when seeding with legumes to inoculate the seeds with nitrogen-fixing bacteria before seeding; such a practice may be particularly important in seeding overburden and mine spoils, which ordinarily are not expected to contain adequate numbers of these bacteria.

2.5 Maintenance

It is expected that two to five years of institutional maintenance will be necessary at revegetated tailings disposal sites before decommissioning. Maintenance will, in general, consist of:

- Reseeding of bare areas in which the initial seeding was not successful;
- Installation and repair of windbreaks, snow fences, water diversion ditches, and livestock fences;
- Supplemental irrigation (if necessary), replacement of mulches, and other erosion control measures.
- Introduction of perennial shrubs and woody species as the second phase of the revegetation procedure, if appropriate for the site and the region.

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3. "Economic Engineering Analysis of U.S. Surface Coal Mines and Effective Land Reclamation," Skelly and Loy, Engineers-Consultants, for U.S. Bureau of Mines, Contract Report S-241049, Washington, D.C., 1975.

APPENDIX O. RADON EXHALATION FROM NATURAL SOILS

This appendix summarizes information concerning radon flux rates from natural soils. For a given concentration of radium in soil and with transient effects of atmospheric changes averaged out, radon exhalation is a function of varying characteristics of soil including moisture content, density, porosity, grain size, vegetative cover, and emanating power. Because these factors vary greatly among soils and rocks, radon surface flux rates from natural soils will vary from one location to another.

Table O.1 summarizes information on radon flux measurements made in the contiguous U.S. by various researchers (Table 4.1 of NUREG/CR-0573, February 1979, prepared by Oak Ridge National Laboratory in support of this document). The flux rates reported are averages of measurements made at 8 separate locations in the U.S. The overall average of these reported values is about 0.8 pCi/m^2-sec (1.2 pCi/m^2-sec, if measurements are weighted by the number of measurements made). An average of about 0.65 pCi/m^2-sec (weighted or unweighted) is obtained if measurements of Western regions, where mining and milling occurs, are considered. These values compare with estimates made of world-wide soil flux rates of 0.4,[1] 0.5[2] and 0.42[3] pCi/m^2-sec.

The measurements reported above and in Table O.1 are averaged values. Table O.2 presents the results of radium concentrations in soils in 7 different western states which indicate the kind of variation that can occur in soils in uranium milling regions. The distribution of radium soil concentrations is log-normal. As such, the proper central measure is the geometric mean. The values in Table O.2 are averages and ranges. The raw data from which Table O.2 was compiled has a geometric mean of 1.2 pCi/gm with a geometric standard deviation of 1.61 pCi/gm. The range of the data is 0.23 to 3.4 pCi/gm, as can be noted from Table O.2. Using these values under the log-normal distribution assumption, the 99% upper confidence limit for radium soil concentration is 4.10 pCi/gm.

The variability in radon flux from natural soils can be inferred from the variability in soil radium concentrations. Although the relationship varies, the correlation between radon flux and radium concentration adheres on the average to approximately 0.6 pCi/m^2-sec per pCi/gm of radium. As discussed above, the rate of radon exhalation depends upon radium concentration and other soil characteristics. A single measure of a particular soil's radon attenuation properties is its diffusion coefficient, D. (See Appendix G-1). The rate of radon exhalation from soil can be predicted by the following equation using D:

$$J = C_{Ra}\,\rho\,E\,\sqrt{\lambda(D/P)}$$

D = effective bulk diffusion coefficient (cm^2/sec)

C_{Ra} = Concentration of radium (pCi/gm)

ρ = density of soil (gm/cc)

E = emanating power

λ = decay constant of radon-222 (2.1×10^{-6} sec^{-1})

P = porosity

As mentioned in Appendix G-1, the following parameter values are appropriate:

$$\rho = 1.6 \text{ gm/cc}$$

$$E = 0.2$$

However, the value of D/P varies with moisture in the soil, among other quantities. Typical soil moistures in the western milling regions range from 6 to 10 percent (Appendix P). Appropriately, the D/P values range from 7.8×10^{-3} cm^2/sec to 2.2×10^{-2} cm^2/sec. Using these values for D/P, a simple multiplicative factor, the specific radon flux factor, can be calculated.

$\underline{D/P = 7.8 \times 10^{-3} \text{ cm}^2/\text{sec}}$

$$J = C_{Ra} \times 1.6 \times 0.2 \times [2.1 \times 10^{-6} \times 7.8 \times 10^{-3}]^{\frac{1}{2}} \times 10^4 \frac{\text{cm}^2}{\text{m}^2}$$

$$J = C_{Ra} \times 0.4 \text{ gm/m}^2\text{-sec}$$

$$\underline{D/P = 2.2 \times 10^{-2}\ \mathrm{cm^2/sec}}$$

$$J = C_{Ra} \times 1.6 \times 0.2 \times [2.1 \times 10^{-6} \times 2.2 \times 10^{-2}]^{\frac{1}{2}} \times 10^{4}\ \frac{\mathrm{cm^2}}{\mathrm{m^2}}$$

$$J = C_{Ra} \times 0.7\ \mathrm{gm/m^2\text{-}sec}$$

As can be noted from the above equations, the specific flux factor can vary from 0.4 to 0.7 gm/m^2-sec in western milling regions. Using the midrange value of 0.55 gm/m^2-sec and the upper confidence limit of soil radium concentration, it is inferred that in approximately 99% of all circumstances, the radon flux should not exceed 2.3 pCi/m^2-sec.

This approach is consistent with the data and observations from Table 0.1. Again using the specific flux factor of 0.55 gm/m^2-sec and the geometric mean of the radium soil concentrations, 1.2 pCi/gm, the corresponding flux would be 0.66 pCi/m^2-sec, which concurs with the previously mentioned average flux in the western milling regions, 0.65 pCi/m^2-sec.

Table 0.1 Radon-222 Flux Measurements in the Contiguous United States

Location	Average reported radon flux pCi/m^2-sec	Reference
Illinois		
Champaign County (472)[a]	1.4	Pearson and Jones (1966)[5]
Argonne (8)	0.56	Pearson and Jones (1966)[5]
Massachusetts		
Lincoln (10)	1.34	Kraner et al. (1964)[6]
New Mexico		
Socorro (10)	0.90	Wilkening and Hand (1960)[7]
Socorro (6)	1.01	Pearson et al. (1965)[8]
Socorro (164)	0.64	Wilkening et al. (1975)[3]
Nevada		
Yucca Flat	0.47	Kraner et al. (1964)[6]
Texas		
Varied Locations (9)	0.27	Wilkening et al. (1975)[3]

[a] Number in parentheses indicates number of separate measurements.

Table 0.2 Radium-226 Background Soil Concentrations in the Western Uranium Milling Areas[a,b]

State	Average ^{226}Ra Concentrations (pCi/g)	Range of ^{226}Ra Concentrations (pCi/g)
Arizona (6)[c]	0.95	0.23-2.0
Colorado (32)	1.4	0.48-3.4
Nevada (6)	1.5	0.89-2.0
New Mexico (13)	1.5	0.72-2.7
Texas (10)	0.89	0.54-1.4
Utah (32)	1.3	0.53-1.9
Wyoming (13)	1.0	0.65-1.7

[a] Compiled from data in "State Background Radiation Levels: Results of Measurements Taken During 1975-1979" ORNL/TM-7343.

[b] Table 0.2 in the Draft GEIS was updated using the reference in footnote a.

[c] Figures in the parenthesis indicate the number of samples.

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APPENDIX P. CALCULATION OF THICKNESSES OF REQUIRED COVER MATERIALS

The calculation of the thicknesses of cover materials required to attenuate radon flux to near-background levels is based upon diffusion theory. The effectiveness of a particular cover material in attenuating radon depends upon the material's ability to restrict the diffusion of radon through it so that the radon gas decays to a solid daughter product before reaching the surface.

The next section of this appendix contains a discussion of general factors influencing radon diffusion through covers. The analytical model and example calculations are given in section 2. It may be neglected with little loss of continuity in using the standard tables presented later. Section 3 contains the final equation used to calculate cover thicknesses presented in several tables as a function of ore grade, tailings moisture and cover moisture.

1.0 GENERAL CONSIDERATIONS

The material properties used to determine radon attenuation are the effective bulk diffusion coefficients (D) and porosities (P) of the cover material and of the tailings. Values of D may be measured experimentally for a given material at its ambient moisture level and expected degree of compaction. Alternatively, D can be estimated solely from the moisture content and porosity of the material, because the large variation (four orders of magnitude) in D with moisture content obscures the much smaller effects on the value of D from other soil properties[1]. Hence, the most important characteristic of cover soils is their ability to retain moisture.

Although soils contain widely varying proportions of the three particle size categories, sand (50-2,000μm), silt (2-50μm), and clay (<2μm), they are generally referred to in terms of the predominant particle size fraction, i.e., clay soils contain greater than 40% clay-sized particles. Because the small clay particles contain various proportions of clay minerals and chemicals, there is a great diversity of clays in nature; however, they all generally have pronounced absorption and adsorption of moisture. Because clays, particularly montmorillonite, can retain significant amounts of moisture for extended periods of time, they are effective in attenuating radon; however, they must be protected from the surface effects of cracking and erosion. As an example of the water retention properties of clay, laboratory measurements of individual heavy clay types have measured hygroscopic water concentrations of 15 to 20%. The hygroscopic water is held as a very thin film and requires the application of greater than 30 to 10,000 bars pressure[2].

A survey of available drilling log information from ten sites in the uranium milling regions in Wyoming, Colorado, New Mexico and Utah yielded ambient moisture concentrations of near-surface clay soils ranging 9-12%, although a few isolated, undisturbed values exceeded 12%. For non-clay soils the survey obtained moisture concentrations ranging from 6 to 10%.

With the moisture concentration in the cover soils, D may be estimated from the following empirical correlation of laboratory data[1]:

$$D/P = 0.106 \exp(-0.261\ M), \qquad (1)$$

where M is the weight-percentage of soil moisture and D has units of cm^2/s. It is possible, using equation (1), to express radon attenuation also in terms of porosities and moistures of the tailings and cover. This correlation is based mainly upon a limited amount of laboratory data, and it could possibly be modified slightly as additional data become available. The basic parameters characterizing the soils are the diffusion coefficient and the porosity. The equations given in the next section are expressed in terms of D and P, but for convenience equation (1) is used in select cases to give the moisture dependence explicitly. The converted equations may undergo slight modification as more research is conducted by the NRC and other organizations.

2.0 TECHNICAL DISCUSSION

Calculation of the thickness of cover materials required to attenuate radon flux to near-background levels is based upon the equation[1]:

$$J_1 = J_0 \exp(-a_1 x_1) \qquad (2)$$

where J_1 = radon flux from the surface after attenuation with the cover (pCi/m^2s)

J_0 = radon flux at the surface of the bare tailings (pCi/m^2s)

x_1 = thickness of the cover material (cm)

a_1 = attenuation constant of cover material (cm^{-1})

$= (\lambda P_1/D_1 h)^{\frac{1}{2}}$

λ = decay constant for Rn-222 ($2.1\times10^{-6}\ s^{-1}$)

P_1 = porosity for cover material.

The function h is given by the following expression:

$$h = \left[1 - \frac{1}{b_1x_1}\ln\left\{\frac{2}{(1 + \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}}) + (1 - \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}})\exp(-2b_1x_1)}\right\}\right]^{-2}, \tag{3}$$

where, $b_1 = (\lambda P_1/D_1)^{\frac{1}{2}}$.

The subscripts o in equation (3) refer to the tailings, and subscripts 1 refer to the cover layer. Equation (2) can also be written as[1]:

$$J_1 = J_0 f \exp(-b_1x_1), \tag{4}$$

where

$$f = \frac{2}{(1 + \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}}) + (1 - \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}})\exp(-2b_1x_1)}, \tag{5}$$

so that equation (3) is

$$h = \left[1 - \frac{1}{b_1x_1}\ln f\right]^{-2}, \tag{6}$$

and, for a given thickness x_1, the surface flux J_1 is calculated from

$$J_1 = \frac{2\,J_0\exp(-b_1x_1)}{(1 + \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}}) + (1 - \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}})\exp(-2b_1x_1)}, \tag{7}$$

When the flux attenuation is specified and the cover thickness must be determined, the following approximate expression is useful[3]:

$$x_1 = \left[\frac{D_1/P_1}{\lambda}\right]^{\frac{1}{2}}\left[\ln(2J_0/J_1) - \ln\left[(1 + \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}}) + (1 - \frac{P_0}{P_1}\left[\frac{D_0/P_0}{D_1/P_1}\right]^{\frac{1}{2}})(J_1/J_0)^2\right]\right] \tag{8}$$

If the diffusion coefficients are expressed in terms of the moistures using equation (1) then equation (8) becomes[3]:

$$x_1 = 2.28\exp(-0.13M_1)\left\{\ln(2J_0/J_1) - \ln[(1 + \frac{P_0}{P_1}\exp(0.13(M_1-M_0))) + (1 - \frac{P_0}{P_1}\exp(0.13(M_1-M_0)))(J_1/J_0)^2]\right\} \qquad (9)$$

where

x_1 = required depth of cover in meters

M_0 = weight-percentage of moisture in tailings

M_1 = weight-percentage of moisture in soil cover

If the flux attenuation is greater than a factor of ten ($J_0/J_1>10$), then equation (9) can be written as:

$$x_1 = 2.28\exp(-0.13M_1)\,[\ln(2J_0/J_1) - \ln[1 + \frac{P_0}{P_1}\exp(0.13(M_1-M_0))]] \qquad (10)$$

Since composite tailings covers are also considered, it is necessary to extend the formalism to accommodate multiple covers.

It is readily shown[1,4] that equations (2) and (4) become:

$$J_n = J_0\exp\left(-\sum_{m=1}^{n} a_m x_m\right) \qquad (11)$$

$$J_n = J_0\left(\prod_{m=1}^{n} f_m\right)\exp\left(-\sum_{m=1}^{n} b_m x_m\right) \qquad (12)$$

if the flux through one cover layer is considered to be the source for the next layer.

These equations define the radon flux from the nth layer exactly, assuming only the absence of radium in the cover layers and the usual boundary conditions. However, for multiple cover layers the effective bulk diffusion coefficient and porosity of the "source" for a given layer must appropriately represent the actual tailings source and all preceeding cover layers. In order to avoid solving a complicated series of coupled differential equations, the effective bulk diffusion coefficient and porosity of the "source" for each layer can be approximated by the weighted average[3]:

$$\frac{D_{sm}}{P_{sm}} = \sum_{i=o}^{m-1}\frac{D_i}{P_i}[1 - \exp(-a_i x_i)]\exp\left(-\sum_{j=i+1}^{m-1} a_i x_i\right) \qquad (13)$$

where

$a_i = (\lambda P_i/D_i h)^{\frac{1}{2}}$

x_i = depth of the ith cover soil

$a_0 = x_0 = 0$

The b_i may be substituted for the a_i with little loss of accuracy. The term $\frac{D_{sm}}{P_{sm}}$ refers to the average value for the underlying cover layers plus the tailings, and the subscript m replaces the subscript 1 in the previous equations.

It should be noted that the calculations assume (a) effectively infinite tailings thickness, (b) negligible radium in the cover layers, (c) the validity of the equation (13) approximation for composite covers and (d) the usual boundary conditions used in solving the differential equations for radon diffusion.[1] Assumption (a) is usually met by tailings piles which exceed about 3 m thickness, causing the factor $\tanh(x_0\,[\lambda P_0/D_0]^{1/2})$ to approach unity.[1] Assumption (b) can cause considerable difference between predicted and measured total fluxes. However, if radium in the cover materials is considered to be a background source, its neglect is justified. Assumptions (c) and (d) have less significant impacts and are discussed elsewhere.[3,4]

The radon flux from the bare tailings source, J_0, is calculated from equation (16) of Appendix G-1.

$$J_0 = [Ra]\,\rho\,E\,(\lambda D_0/P_0)^{1/2} \times 10^4 \qquad (14)$$

where $[Ra]$ = concentration of radium-226 in the tailings solids (pCi/g)

ρ = density of the tailings solids (g/cm^3)

E = emanating power of tailings (dimensionless)

D_0 = effective bulk diffusion coefficient for radon in the tailings (cm^2/s)

P_0 = porosity or void fraction in tailings solids (dimensionless)

The values for computing J_0 will vary from mill to mill depending on the characteristics of the tailings produced. The following typical values are assumed in order to define the radon flux for the bare tailings for the three tailings cover examples:

$[Ra] = 280$ pCi/g

$\rho = 1.6$ g/cm^3

$E = 0.2$

$D_0/P_0 = 4.7 \times 10^{-2}$ cm^2/s

$P_0 = 0.25$

The radon flux from the surface of the uncovered tailings is calculated by equation (13) as

$$J_0 = (280)(1.6)(0.2)[(2.1 \times 10^{-6})(0.047)]^{1/2}(10^4\text{cm}^2/\text{m}^2)$$

$$= 280 \text{ pCi/m}^2\text{s}$$

Three examples are provided to illustrate the methods for calculating cover thicknesses as described in this section. The first is for the case of known diffusion coefficients and porosities; the second is for the case of known moistures and porosities; and the third is for a two-layered cover with known moistures.

Example 1

It is assumed that the tailings pile is as described above and that a cover material is available which has the following properties:

$\frac{D_1}{P_1} = 8.2 \times 10^{-3}$ cm^2/s (Wyoming Background Soil #1, Chapter 9, Table 9.11)

$P_1 = 0.3$

The flux attenuation with 3 m of cover material is calculated from equation (7).

$$J_1 = \frac{2(280)(8.2 \times 10^{-3})}{2.99 - 2.0 \times 10^{-4}}$$

$$J_1 = 1.5 \text{ pCi/m}^2\text{s}$$

So the 3 m cover reduces the radon flux below the proposed limit. If the simple exponential attentuation formula would have been used (i.e., h=1), then J_1 would have been 2.3 pCi/m^{2}s which is above the proposed limit.

What x_1 yields a J_1 of 2 pCi/m^{2}s? This is determined from equation (8):

$$x_1 = 0.63[5.64 - 1.10]$$

$$x_1 = 2.8 \text{ m}$$

Example 2

What thickness of 10% moisture cover soil will attenuate the radon flux from an 8% moisture tailings pile to a value of 2 pCi/m^{2}s? The porosities are the same, and all other tailings parameters are as given previously.

Equation (10) will provide the answer, once J_0 is determined from equation (14):

$$\frac{D_0}{P_0} = 0.106 \exp(-0.261(8))$$

$$\frac{D_0}{P_0} = 0.013 \text{ cm}^2/\text{sec}$$

$$J_0 = (280)(1.6)(0.2)[(2.1 \times 10^{-6})(0.013)]^{\frac{1}{2}} \times 10^4$$

$$J_0 = 149 \text{ pCi/m}^2\text{s}$$

and

$$x_1 = (0.62)(5.00 - 0.832)$$

$$x_1 = 2.6 \text{ m}$$

Example 3

The tailings pile described in example 2 is to be covered with 1 m of a good quality clay capable of retaining 12% moisture and sufficient overburden at 6% moisture to achieve a surface flux of 2 pCi/m^{2}s. What thickness of overburden should be used? Assume equal porosities for all materials.

First, determine the diffusion coefficients:

tailings $\frac{D_0}{P_0} = 0.013$ cm^2/s

clay $\frac{D_1}{P_1} = 0.0046$ cm^2/s

overburden $\frac{D_2}{P_2} = 0.022$ cm^2/s

Then, calculate the attenuation through the clay component using equations (4) and (5)

$$J_1 = (149) \left[\frac{2}{2.682 - (0.682)(0.014)} \right](0.119)$$

$$J_1 = 13 \text{ pCi/m}^2\text{s.}$$

Now, determine the effective diffusion coefficient for the source term to the overburden (the source is now the tailings and clay) using equation (13).

$$\frac{Ds_2}{Ps_2} = \frac{D_0}{P_0} \exp(-a_1x_1) + \frac{D_1}{P_1} [1 - \exp(-a_1x_1)]$$

$$\frac{Ds_2}{Ps_2} = (0.013)(0.088) + (0.0046)(1 - 0.088)$$

$$\frac{Ds_2}{Ps_2} \doteq 0.0053 \text{ cm}^2/\text{s}$$

This expression is substituted for D_0/P_0 and $J_1 = 13$ is substituted for J_0 in equation (8).

$$x_2 = (1.02)[2.56 - \ln[1.491 + (1 - 0.491)(0.024)]]$$

$$x_2 = 2.2 \text{ m} = \text{overburden thickness}$$

So the total cover thickness is 3.2 m.

3.0 COVER THICKNESS DETERMINATIONS

As indicated in section 2, the selection of a proper depth of cover for tailings can be greatly facilitated using the following assumptions:

$P_0 = P_1$

$E = 0.2$

$\rho = 1.6 \text{ g/cm}^3$

$M_0 = 3.1\%$

[Ra] = 280 pCi/g (ore grade = 0.10%)

Equation (10) can then be written as

$$x_1 = 2.28 \exp(-0.13M_1) [\ln(560/J_1) - \ln[1 + 0.668\exp(0.13M_1)]] \qquad (15)$$

Values of the cover thickness for various fluxes and cover moistures are given in Chapter 9, Figure 9.1. Simple covers with moistures 9% and less require more than 3 m to attenuate the radon to a surface flux of 2 pCi/m²s.

The bare tailings flux can be expressed explicitly as a function of the ore grade G (%U_3O_8), and the parameters E, M_0, and M_1. The resulting form for equation (9), with $P_0 = P_1$ and $J_1 = 2$ pCi/m²s, is

$$x_1 = 2.28 \exp(-0.13M_1) [\ln[(21{,}000GE)\exp(-0.13M_0)] - \ln[1 + \exp(0.13(M_1 - M_0)) + \frac{\left(1 - \exp(0.13(M_1 - M_0))\right)}{[(10{,}500GE)\exp(-0.13M_0)]^2}]] \qquad (16)$$

Results of this expression are tabulated in Tables P.1 - P.11 for G from 0.05 - 0.30, M_0 from 3 - 15%, M_1 from 5 - 15% and E = 0.2.* The ranges of these parameters are compatible for ambient soils of the western United States milling and mining regions.

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*Reference 1 investigates properties of alkaline (Ambrosia Lake Tailings #3) as well as acid leach tailings. An emanating power of 0.2 is applicable to both types of tailings (See reference 1, Table 5-2).

The D/P values are also given in Tables P.1 - P.11 so that they may be useful even if the moisture correlation of equation (1) is modified with additional information. Once the correct D/P has been determined for the tailings and cover soil, then the tables and the figure give the correct thicknesses.

Two examples will illustrate the use of the tables.

Example 1

A uranium mill processes ore which is 0.12% U_3O_8. The tailings will be stored in an impoundment where the long-term moisture concentration in the tailings is 8%. What level of moisture should the cover soil retain in order to necessitate only 3 m of cover?

Solution

1. Locate the 0.12% ore grade table.
2. Find the 8% tailings moisture in the first column.
3. Follow the 8% row horizontally into the body of the table to the 3.1 m value.
4. Move vertically upward to the cover moisture (%) row (top row) and locate the 9% value.

The soil must retain 9% moisture in the long term in order to insure the adequacy of 3.1 m of soil cover.

Example 2

A uranium mill which processes 0.10% U_3O_8 ore is limited to local soils for covers to be used to attenuate radon from the tailings. The local soils, as well as tailings, are predicted to retain 9% moisture in the long term. What is the minimum depth of soil cover necessary to achieve the limit of 2 pCi/m^2s radon flux above background?

Solution

1. Locate the 0.10% ore grade table.
2. Find the 9% tailings moisture in the first column.
3. Move horizontally into the body of the table until directly under the 9% cover moisture figure in the top row.
4. The value in the intersection of the 9% row and 9% column is 3.0 m.

The mill operator would need 3 m of cover soil to insure the radon flux would not exceed 2 pCi/m^2s.

The cover thickness variation with ore grade, tailings moisture and porosity ratio (P_0/P_1) is generally of second order[3]. The following trends[3] are useful in estimating the magnitude of these secondary effects.

For a surface radon flux of 2 pCi/m^2s, the cover thickness decreases by about 5 cm for every

1% increase in tailings moisture

or, 0.01 wt% decrease in ore grade

or, 0.1 increase in porosity ratio.

The methods described here for determining tailings cover thicknesses were selected to provide a simple, but accurate, standardized approach to licensing. The staff considers that the level of detail and sophistication involved with these methods is appropriate, given the variability and uncertainties existing for these parameters. However, in some cases slight modification of these methods may be appropriate. For example, if the method of depositing tailings in the impoundment was done in such a way that sand fractions of tailings were deposited in thick layers above slime fractions, estimating flux from the bare tailings source (J_0) would warrant assumptions other than homogeneous mixing of the tailings.

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .05

TABLE P. 1

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		4.9	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1.4	1.2	1.0
5.0	.0287		4.8	4.1	3.6	3.1	2.6	2.3	1.9	1.7	1.4	1.2	1.0
6.0	.0221		4.7	4.1	3.5	3.0	2.6	2.2	1.9	1.6	1.4	1.2	1.0
7.0	.0171		4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.6	1.4	1.2	1.0
8.0	.0131		4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4	1.2	1.0
9.0	.0101		4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6	1.4	1.2	1.0
10.0	.0078		4.3	3.8	3.3	2.8	2.4	2.1	1.8	1.6	1.3	1.1	1.0
11.0	.0060		4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1	1.0
12.0	.0046		4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3	1.1	.9
13.0	.0036		4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3	1.1	.9
14.0	.0027		3.9	3.4	2.9	2.6	2.2	1.9	1.7	1.4	1.2	1.1	.9
15.0	.0021		3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2	1.0	.9

ORE GRADE IS .06

TABLE P. 2

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		5.2	4.4	3.8	3.3	2.8	2.4	2.1	1.8	1.5	1.3	1.1
5.0	.0287		5.0	4.3	3.7	3.2	2.8	2.4	2.0	1.8	1.5	1.3	1.1
6.0	.0221		4.9	4.3	3.7	3.2	2.7	2.4	2.0	1.7	1.5	1.3	1.1
7.0	.0171		4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3	1.1
8.0	.0131		4.8	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.4	1.2	1.1
9.0	.0101		4.7	4.0	3.5	3.0	2.6	2.3	1.9	1.7	1.4	1.2	1.0
10.0	.0078		4.6	4.0	3.4	3.0	2.6	2.2	1.9	1.6	1.4	1.2	1.0
11.0	.0060		4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4	1.2	1.0
12.0	.0046		4.3	3.8	3.3	2.8	2.5	2.1	1.8	1.6	1.4	1.2	1.0
13.0	.0036		4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1	1.0
14.0	.0027		4.1	3.6	3.1	2.7	2.3	2.0	1.8	1.5	1.3	1.1	1.0
15.0	.0021		4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3	1.1	.9

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .08

TABLE P. 3

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		5.5	4.7	4.1	3.5	3.0	2.6	2.2	1.9	1.6	1.4	1.2
5.0	.0287		5.4	4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.6	1.4	1.2
6.0	.0221		5.3	4.6	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4	1.2
7.0	.0171		5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.8	1.6	1.4	1.2
8.0	.0131		5.1	4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6	1.3	1.2
9.0	.0101		5.0	4.3	3.8	3.3	2.8	2.4	2.1	1.8	1.5	1.3	1.1
10.0	.0078		4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1
11.0	.0060		4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3	1.1
12.0	.0046		4.7	4.1	3.5	3.1	2.7	2.3	2.0	1.7	1.5	1.3	1.1
13.0	.0036		4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3	1.1
14.0	.0027		4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.7	1.4	1.2	1.1
15.0	.0021		4.3	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2	1.0

ORE GRADE IS .10

TABLE P. 4

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		5.8	5.0	4.3	3.7	3.2	2.7	2.4	2.0	1.7	1.5	1.3
5.0	.0287		5.6	4.9	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3
6.0	.0221		5.5	4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.2
7.0	.0171		5.5	4.7	4.1	3.5	3.1	2.6	2.3	2.0	1.7	1.4	1.2
8.0	.0131		5.4	4.7	4.0	3.5	3.0	2.6	2.2	1.9	1.7	1.4	1.2
9.0	.0101		5.3	4.6	4.0	3.4	3.0	2.6	2.2	1.9	1.6	1.4	1.2
10.0	.0078		5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4	1.2
11.0	.0060		5.1	4.4	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2
12.0	.0046		5.0	4.3	3.7	3.3	2.8	2.4	2.1	1.8	1.6	1.4	1.2
13.0	.0036		4.8	4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1
14.0	.0027		4.7	4.1	3.6	3.1	2.7	2.3	2.0	1.8	1.5	1.3	1.1
15.0	.0021		4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3	1.1

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .12

TABLE P. 5

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.0	5.2	4.5	3.9	3.3	2.9	2.5	2.1	1.8	1.6	1.3
5.0	.0287		5.8	5.1	4.4	3.8	3.3	2.8	2.4	2.1	1.8	1.5	1.3
6.0	.0221		5.8	5.0	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3
7.0	.0171		5.7	4.9	4.3	3.7	3.2	2.8	2.4	2.0	1.8	1.5	1.3
8.0	.0131		5.6	4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3
9.0	.0101		5.5	4.8	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3
10.0	.0078		5.4	4.7	4.1	3.5	3.1	2.6	2.3	2.0	1.7	1.5	1.3
11.0	.0060		5.3	4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.7	1.4	1.2
12.0	.0046		5.2	4.5	3.9	3.4	3.0	2.6	2.2	1.9	1.7	1.4	1.2
13.0	.0036		5.1	4.4	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2
14.0	.0027		4.9	4.3	3.8	3.3	2.8	2.5	2.1	1.8	1.6	1.4	1.2
15.0	.0021		4.8	4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.6	1.4	1.2

ORE GRADE IS .14

TABLE P. 6

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.2	5.3	4.6	4.0	3.4	3.0	2.5	2.2	1.9	1.6	1.4
5.0	.0287		6.0	5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4
6.0	.0221		5.9	5.1	4.5	3.9	3.3	2.9	2.5	2.1	1.8	1.6	1.4
7.0	.0171		5.9	5.1	4.4	3.8	3.3	2.8	2.5	2.1	1.8	1.6	1.3
8.0	.0131		5.8	5.0	4.3	3.8	3.3	2.8	2.4	2.1	1.8	1.6	1.3
9.0	.0101		5.7	4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.5	1.3
10.0	.0078		5.6	4.8	4.2	3.6	3.2	2.7	2.4	2.0	1.8	1.5	1.3
11.0	.0060		5.5	4.8	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3
12.0	.0046		5.4	4.7	4.1	3.5	3.1	2.7	2.3	2.0	1.7	1.5	1.3
13.0	.0036		5.2	4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3
14.0	.0027		5.1	4.5	3.9	3.4	2.9	2.6	2.2	1.9	1.7	1.4	1.2
15.0	.0021		5.0	4.4	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .16

TABLE P. 7

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.3	5.5	4.7	4.1	3.5	3.0	2.6	2.3	1.9	1.7	1.4
5.0	.0287		6.2	5.4	4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.6	1.4
6.0	.0221		6.1	5.3	4.6	4.0	3.4	3.0	2.6	2.2	1.9	1.6	1.4
7.0	.0171		6.0	5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4
8.0	.0131		5.9	5.1	4.5	3.9	3.3	2.9	2.5	2.2	1.9	1.6	1.4
9.0	.0101		5.8	5.1	4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6	1.4
10.0	.0078		5.7	5.0	4.3	3.8	3.3	2.8	2.4	2.1	1.8	1.6	1.4
11.0	.0060		5.6	4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.6	1.3
12.0	.0046		5.5	4.8	4.2	3.6	3.2	2.7	2.4	2.1	1.8	1.5	1.3
13.0	.0036		5.4	4.7	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5	1.3
14.0	.0027		5.3	4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5	1.3
15.0	.0021		5.2	4.5	3.9	3.4	3.0	2.6	2.2	1.9	1.7	1.5	1.3

ORE GRADE IS .18

TABLE P. 8

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.5	5.6	4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5
5.0	.0287		6.3	5.5	4.7	4.1	3.5	3.1	2.6	2.3	2.0	1.7	1.4
6.0	.0221		6.2	5.4	4.7	4.1	3.5	3.0	2.6	2.3	1.9	1.7	1.4
7.0	.0171		6.2	5.3	4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.7	1.4
8.0	.0131		6.1	5.3	4.6	4.0	3.4	3.0	2.6	2.2	1.9	1.6	1.4
9.0	.0101		6.0	5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4
10.0	.0078		5.9	5.1	4.4	3.9	3.3	2.9	2.5	2.2	1.9	1.6	1.4
11.0	.0060		5.8	5.0	4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6	1.4
12.0	.0046		5.7	4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.6	1.4
13.0	.0036		5.5	4.8	4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.6	1.3
14.0	.0027		5.4	4.7	4.1	3.6	3.1	2.7	2.4	2.0	1.8	1.5	1.3
15.0	.0021		5.3	4.6	4.0	3.5	3.1	2.7	2.3	2.0	1.7	1.5	1.3

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .20

TABLE P. 9

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.6	5.7	4.9	4.3	3.7	3.2	2.7	2.4	2.0	1.7	1.5
5.0	.0287		6.4	5.6	4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.7	1.5
6.0	.0221		6.4	5.5	4.8	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5
7.0	.0171		6.3	5.5	4.7	4.1	3.5	3.1	2.7	2.3	2.0	1.7	1.5
8.0	.0131		6.2	5.4	4.7	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.4
9.0	.0101		6.1	5.3	4.6	4.0	3.5	3.0	2.6	2.2	1.9	1.7	1.4
10.0	.0078		6.0	5.2	4.5	3.9	3.4	3.0	2.6	2.2	1.9	1.7	1.4
11.0	.0060		5.9	5.1	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6	1.4
12.0	.0046		5.8	5.0	4.4	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4
13.0	.0036		5.7	4.9	4.3	3.7	3.3	2.8	2.5	2.1	1.8	1.6	1.4
14.0	.0027		5.6	4.8	4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.6	1.4
15.0	.0021		5.4	4.7	4.1	3.6	3.1	2.7	2.4	2.1	1.8	1.5	1.3

ORE GRADE IS .25

TABLE P.10

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		6.9	5.9	5.1	4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6
5.0	.0287		6.7	5.8	5.0	4.4	3.8	3.3	2.8	2.4	2.1	1.8	1.6
6.0	.0221		6.6	5.8	5.0	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.5
7.0	.0171		6.5	5.7	4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.5
8.0	.0131		6.5	5.6	4.9	4.2	3.7	3.2	2.7	2.4	2.0	1.8	1.5
9.0	.0101		6.4	5.5	4.8	4.2	3.6	3.1	2.7	2.3	2.0	1.8	1.5
10.0	.0078		6.3	5.4	4.7	4.1	3.6	3.1	2.7	2.3	2.0	1.7	1.5
11.0	.0060		6.2	5.4	4.7	4.1	3.5	3.1	2.7	2.3	2.0	1.7	1.5
12.0	.0046		6.0	5.3	4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5
13.0	.0036		5.9	5.2	4.5	3.9	3.4	3.0	2.6	2.2	1.9	1.7	1.4
14.0	.0027		5.8	5.1	4.4	3.9	3.4	2.9	2.5	2.2	1.9	1.7	1.4
15.0	.0021		5.7	5.0	4.3	3.8	3.3	2.9	2.5	2.2	1.9	1.6	1.4

TABLES OF REQUIRED DEPTHS FOR RADON ATTENUATION (METERS)

ORE GRADE IS .30

TABLE P.11

COVER MOISTURE (%)/DIFFUSION COEFFICIENT (CM**2 PER SEC)

TAILINGS MOISTURE (%)	DIFFUSION COEFFICIENT (CM**2/SEC)	(%)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
		D/P	.0287	.0221	.0171	.0131	.0101	.0078	.0060	.0046	.0036	.0027	.0021
3.0	.0484		7.1	6.1	5.3	4.6	4.0	3.4	3.0	2.6	2.2	1.9	1.6
5.0	.0287		6.9	6.0	5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6
6.0	.0221		6.8	5.9	5.2	4.5	3.9	3.4	2.9	2.5	2.2	1.9	1.6
7.0	.0171		6.8	5.9	5.1	4.4	3.8	3.3	2.9	2.5	2.1	1.8	1.6
8.0	.0131		6.7	5.8	5.0	4.4	3.8	3.3	2.8	2.5	2.1	1.8	1.6
9.0	.0101		6.6	5.7	5.0	4.3	3.7	3.3	2.8	2.4	2.1	1.8	1.6
10.0	.0078		6.5	5.6	4.9	4.3	3.7	3.2	2.8	2.4	2.1	1.8	1.6
11.0	.0060		6.4	5.6	4.8	4.2	3.7	3.2	2.7	2.4	2.1	1.8	1.5
12.0	.0046		6.3	5.5	4.8	4.1	3.6	3.1	2.7	2.4	2.0	1.8	1.5
13.0	.0036		6.2	5.4	4.7	4.1	3.5	3.1	2.7	2.3	2.0	1.7	1.5
14.0	.0027		6.0	5.3	4.6	4.0	3.5	3.0	2.6	2.3	2.0	1.7	1.5
15.0	.0021		5.9	5.2	4.5	3.9	3.4	3.0	2.6	2.2	2.0	1.7	1.5

References

1. V. C. Rogers, et. al., "Characterization of Uranium Tailings Cover Materials for Radon Flux Reduction" NUREG/CR-1081 (March, 1980).

2. R. N. Yong and B. P Warkentin, Introduction to Soil Behavior, MacMillan, New York (1966).

3. V. C. Rogers and K. K. Nielson, "Determination of Radon Attenuation Through Cover Materials," Unpublished.

APPENDIX Q. URANIUM MILL TAILINGS RADIATION CONTROL ACT OF 1978

Public Law 95-604
95th Congress

An Act

Nov. 8, 1978
[H.R. 13650]

To authorize the Secretary of Energy to enter into cooperative agreements with certain States respecting residual radioactive material at existing sites, to provide for the regulation of uranium mill tailings under the Atomic Energy Act of 1954, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

Uranium Mill Tailings Radiation Control Act of 1978.
42 USC 7901 note.

SHORT TITLE AND TABLE OF CONTENTS

SECTION 1. This Act may be cited as the "Uranium Mill Tailings Radiation Control Act of 1978".

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FINDINGS AND PURPOSES

42 USC 7901.

SEC. 2. (a) The Congress finds 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 the protection of the public health, safety, and welfare and the regulation of interstate commerce require that every reasonable effort 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 from such tailings.

(b) The purposes of this Act are to provide—

(1) in cooperation with the interested States, Indian tribes, and the persons who own or control inactive mill tailings sites, a program of assessment and remedial action at such sites, including, where appropriate, the reprocessing of tailings to extract residual uranium and other mineral values where practicable, in order to stabilize and control such tailings in a safe and environmentally sound manner and to minimize or eliminate radiation health hazards to the public, and

(2) a program to regulate mill tailings during uranium or thorium ore processing at active mill operations and after termination of such operations in order to stabilize and control such tailings in a safe and environmentally sound manner and to minimize or eliminate radiation health hazards to the public.

TITLE I—REMEDIAL ACTION PROGRAM

DEFINITIONS

42 USC 7911.

SEC. 101. For purposes of this title—

(1) The term "Secretary" means the Secretary of Energy.

(2) The term "Commission" means the Nuclear Regulatory Commission.

(3) The term "Administrator" means the Administrator of the Environmental Protection Agency.

(4) The term "Indian tribe" means any tribe, band, clan, group, pueblo, or community of Indians recognized as eligible for services provided by the Secretary of the Interior to Indians.

(5) The term "person" means any individual, association, partnership, corporation, firm, joint venture, trust, government entity, and any other entity, except that such term does not include any Indian or Indian tribe.

(6) The term "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—

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

42 USC 2011 note.
42 USC 2021.

(ii) a license (issued by the 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 such 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—

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

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

Any ownership or control of an area by a Federal agency which is acquired pursuant to a cooperative agreement under this title shall not be treated as ownership or control by such agency for purposes of subparagraph (A)(i). A license for the production of any uranium product from residual radioactive materials shall not be treated as a license for production from ores within the meaning of subparagraph (A)(ii) if such production is in accordance with section 108(b).

(7) The term "residual radioactive material" means—

(A) waste (which the Secretary determines to be radioactive) in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores; and

(B) other waste (which the Secretary determines to be radioactive) at a processing site which relate to such processing, including any residual stock of unprocessed ores or low-grade materials.

(8) The term "tailings" means the remaining portion of a metal-bearing ore after some or all of such metal, such as uranium, has been extracted.

(9) The term "Federal agency" includes any executive agency as defined in section 105 of title 5 of the United States Code.

(10) The term "United States" means the 48 contiguous States and Alaska, Hawaii, Puerto Rico, the District of Columbia, and the territories and possessions of the United States.

DESIGNATION OF PROCESSING SITES

42 USC 7912.

SEC. 102. (a)(1) As soon as practicable, but no later than one year after enactment of this Act, the Secretary shall designate processing sites at or near the following locations:

Salt Lake City, Utah
Green River, Utah
Mexican Hat, Utah
Durango, Colorado
Grand Junction, Colorado
Rifle, Colorado (two sites)
Gunnison, Colorado
Naturita, Colorado
Maybell, Colorado
Slick Rock, Colorado (two sites)
Shiprock, New Mexico
Ambrosia Lake, New Mexico
Riverton, Wyoming
Converse County, Wyoming
Lakeview, Oregon
Falls City, Texas
Tuba City, Arizona
Monument Valley, Arizona
Lowman, Idaho
Cannonsburg, Pennsylvania

Remedial action.

Subject to the provisions of this title, the Secretary shall complete remedial action at the above listed sites before his authority terminates under this title. The Secretary shall within one year of the date of enactment of this Act also designate all other processing sites within the United States which he determines requires remedial action to carry out the purposes of this title. In making such designation, the Secretary shall consult with the Administrator, the Commission, and the affected States, and in the case of Indian lands, the appropriate Indian tribe and the Secretary of the Interior.

(2) As part of his designation under this subsection, the Secretary, in consultation with the Commission, shall determine the boundaries of each such site.

86 Stat. 222.

(3) No site or structure with respect to which remedial action is authorized under Public Law 92-314 in Grand Junction, Colorado, may be designated by the Secretary as a processing site under this section.

Health hazard assessment.

(b) Within one year from the date of the enactment of this Act, the Secretary shall assess the potential health hazard to the public from the residual radioactive materials at designated processing sites. Based upon such assessment, the Secretary shall, within such one year period, establish priorities for carrying out remedial action at each such site. In establishing such priorities, the Secretary shall rely primarily on the advice of the Administrator.

Notification.

(c) Within thirty days after making designations of processing sites and establishing the priorities for such sites under this section, the Secretary shall notify the Governor of each affected State, and, where appropriate, the Indian tribes and the Secretary of the Interior.

(d) The designations made, and priorities established, by the Secretary under this section shall be final and not be subject to judicial review.

(e)(1) The designation of processing sites within one year after enactment under this section shall include, to the maximum extent practicable, the areas referred to in section 101(6)(B).

(2) Notwithstanding the one year limitation contained in this section, the Secretary may, after such one year period, include any area described in section 101(6)(B) as part of a processing site designated under this section if he determines such inclusion to be appropriate to carry out the purposes of this title.

STATE COOPERATIVE AGREEMENTS

42 USC 7913.

SEC. 103. (a) After notifying a State of the designation referred to in section 102 of this title, the Secretary subject to section 113, is authorized to enter into cooperative agreements with such State to perform remedial actions at each designated processing site in such State (other than a site located on Indian lands referred to in section 105). The Secretary shall, to the greatest extent practicable, enter into such agreements and carry out such remedial actions in accordance with the priorities established by him under section 102. The Secretary shall commence preparations for cooperative agreements with respect to each designated processing site as promptly as practicable following the designation of each site.

Terms and Conditions.

(b) Each cooperative agreement under this section shall contain such terms and conditions as the Secretary deems appropriate and consistent with the purposes of this Act, including, but not limited to, a limitation on the use of Federal assistance to those costs which are directly required to complete the remedial action selected pursuant to section 108.

Written consent.

(c)(1) Except where the State is required to acquire the processing site as provided in subsection (a) of section 104, each cooperative agreement with a State under section 103 shall provide that the State shall obtain, in a form prescribed by the Secretary, written consent from any person holding any record interest in the designated processing site for the Secretary or any person designated by him to perform remedial action at such site.

Waiver.

(2) Such written consent shall include a waiver by each such person on behalf of himself, his heirs, successors, and assigns—

(A) releasing the United States of any liability or claim thereof by such person, his heirs, successors, and assigns concerning such remedial action, and

(B) holding the United States harmless against any claim by such person on behalf of himself, his heirs, successors, or assigns arising out of the performance of any such remedial action.

(d) Each cooperative agreement under this section shall require the State to assure that the Secretary, the Commission, and the Administrator and their authorized representatives have a permanent right of entry at any time to inspect the processing site and the site provided pursuant to section 104(b)(1) in furtherance of the provisions of this title and to carry out such agreement and enforce this Act and any rules prescribed under this Act. Such right of entry under this section or section 106 into an area described in section 101(6)(B) shall terminate on completion of the remedial action, as determined by the Secretary.

(e) Each agreement under this section shall take effect only upon the concurrence of the Commission with the terms and conditions thereof.

(f) The Secretary may, in any cooperative agreement entered into under this section or section 105, provide for reimbursement of the actual costs, as determined by the Secretary, of any remedial action performed with respect to so much of a designated processing site as is described in section 101(6)(B). Such reimbursement shall be made only to a property owner of record at the time such remedial action was undertaken and only with respect to costs incurred by such property owner. No such reimbursement may be made unless—

(1) such remedial action was completed prior to enactment of this Act, and unless the application for such reimbursement was filed by such owner within one year after an agreement under this section or section 106 is approved by the Secretary and the Commission, and

(2) the Secretary is satisfied that such action adequately achieves the purposes of this Act with respect to the site concerned and is consistent with the standards established by the Administrator pursuant to section 275(a) of the Atomic Energy Act of 1954.

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ACQUISITION AND DISPOSITION OF LANDS AND MATERIALS

42 USC 7914.

SEC. 104. (a) Each cooperative agreement under section 103 shall require the State, where determined appropriate by the Secretary with the concurrence of the Commission, to acquire any designated processing site, including where appropriate any interest therein. In determining whether to require the State to acquire a designated processing site or interest therein, consideration shall be given to the prevention of windfall profits.

Residual radioactive material, removal.

(b)(1) If the Secretary with the concurrence of the Commission determines that removal of residual radioactive material from a processing site is appropriate, the cooperative agreement shall provide that the State shall acquire land (including, where appropriate, any interest therein) to be used as a site for the permanent disposition and stabilization of such residual radioactive materials in a safe and environmentally sound manner.

(2) Acquisition by the State shall not be required under this subsection if a site located on land controlled by the Secretary or made available by the Secretary of the Interior pursuant to section 106(a)(2) is designated by the Secretary, with the concurrence of the Commission, for such disposition and stabilization.

(c) No State shall be required under subsection (a) or (b) to acquire any real property or improvement outside the boundaries of—

(1) that portion of the processing site which is described in section 101(6)(A), and

(2) the site used for disposition of the residual radioactive materials.

Notification.

Rules and regulations.

(d) In the case of each processing site designated under this title other than a site designated on Indian land, the State shall take such action as may be necessary, and pursuant to regulations of the Secretary under this subsection, to assure that any person who purchases such a processing site after the removal of radioactive materials from such site shall be notified in an appropriate manner prior to such purchase, of the nature and extent of residual radioactive materials removed from the site, including notice of the date when such action took place, and the condition of such site after such action. If the State is the owner of such site, the State shall so notify any prospective purchaser before entering into a contract, option, or other arrangement to sell or otherwise dispose of such site. The Secretary shall issue appropriate rules and regulations to require notice in the local land records of the residual radioactive materials which were located at any processing site and notice of the nature and extent of residual radioactive materials removed from the site, including notice of the date when such action took place.

(e)(1) The terms and conditions of any cooperative agreement with a State under section 103 shall provide that in the case of any lands or interests therein acquired by the State pursuant to subsection (a), the State, with the concurrence of the Secretary and the Commission, may—

(A) sell such lands and interests,

(B) permanently retain such land and interests in lands (or donate such lands and interests therein to another governmental entity within such State) for permanent use by such State or entity solely for park, recreational, or other public purposes, or

(C) transfer such lands and interests to the United States as provided in subsection (f).

No lands may be sold under subparagraph (A) without the consent of the Secretary and the Commission. No site may be sold under subparagraph (A) or retained under subparagraph (B) if such site is used for the disposition of residual radioactive materials.

(2) Before offering for sale any lands and interests therein which comprise a processing site, the State shall offer to sell such lands and interests at their fair market value to the person from whom the State acquired them.

(f)(1) Each agreement under section 103 shall provide that title to—

(A) the residual radioactive materials subject to the agreement, and

(B) any lands and interests therein which have been acquired by the State, under subsection (a) or (b), for the disposition of such materials,

shall be transferred by the State to the Secretary when the Secretary (with the concurrence of the Commission) determines that remedial action is completed in accordance with the requirements imposed pursuant to this title. No payment shall be made in connection with the transfer of such property from funds appropriated for purposes of this Act other than payments for any administrative and legal costs incurred in carrying out such transfer.

(2) Custody of any property transferred to the United States under this subsection shall be assumed by the Secretary or such Federal agency as the President may designate. Notwithstanding any other provision of law, upon completion of the remedial action program authorized by this title, such property and minerals shall be maintained pursuant to a license issued by the Commission in such manner as will protect the public health, safety, and the environment. The Commission may, pursuant to such license or by rule or order, require the Secretary or other Federal agency having custody of such property and minerals to undertake such monitoring, maintenance, and emergency measures necessary to protect public health and safety and other actions as the Commission deems necessary to comply with the standards of section 275(a) of the Atomic Energy Act of 1954. The Secretary or such other Federal agency is authorized to carry out maintenance, monitoring and emergency measures under this subsection, but shall take no other action pursuant to such license, rule or order with respect to such property and minerals unless expressly authorized by Congress after the date of enactment of this Act. The United States shall not transfer title to property or interest therein acquired under this subsection to any person or State, except as provided in subsection (h).

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(g) Each agreement under section 103 which permits any sale described in subsection (e)(1)(A) shall provide for the prompt reimbursement to the Secretary from the proceeds of such sale. Such reimbursement shall be in an amount equal to the lesser of—

(1) that portion of the fair market value of the lands or interests therein which bears the same ratio to such fair market value as the Federal share of the costs of acquisition by the State to such lands or interest therein bears to the total cost of such acquisition, or

(2) the total amount paid by the Secretary with respect to such acquisition.

Fair market value.

The fair market value of such lands or interest shall be determined by the Secretary as of the date of the sale by the State. Any amounts received by the Secretary under this title shall be deposited in the Treasury of the United States as miscellaneous receipts.

(h) No provision of any agreement under section 103 shall prohibit the Secretary of the Interior, with the concurrence of the Secretary of Energy and the Commission, from disposing of any subsurface mineral rights by sale or lease (in accordance with laws of the United States applicable to the sale, lease, or other disposal of such rights) which are associated with land on which residual radioactive materials are disposed and which are transferred to the United States as required under this section if the Secretary of the Interior takes such action as the Commission deems necessary pursuant to a license issued by the Commission to assure that the residual radioactive materials will not be disturbed by reason of any activity carried on following such disposition. If any such materials are disturbed by any such activity, the Secretary of the Interior shall insure, prior to the disposition of the minerals, that such materials will be restored to a safe and environmentally sound condition as determined by the Commission, and that the costs of such restoration will be borne by the person acquiring such rights from the Secretary of the Interior or from his successor or assign.

INDIAN TRIBE COOPERATIVE AGREEMENTS

42 USC 7915.

SEC. 105. (a) After notifying the Indian tribe of the designation pursuant to section 102 of this title, the Secretary, in consultation with the Secretary of the Interior, is authorized to enter into a cooperative agreement, subject to section 113, with any Indian tribe to perform remedial action at a designated processing site located on land of such Indian tribe. The Secretary shall, to the greatest extent practicable, enter into such agreements and carry out such remedial actions in accordance with the priorities established by him under section 102. In performing any remedial action under this section and in carrying out any continued monitoring or maintenance respecting residual radioactive materials associated with any site subject to a cooperative agreement under this section, the Secretary shall make full use of any qualified members of Indian tribes resident in the vicinity of any such site. Each such agreement shall contain such terms and conditions as the Secretary deems appropriate and consistent with the purposes of this Act. Such terms and conditions shall require the following:

Terms and conditions.

(1) The Indian tribe and any person holding any interest in such land shall execute a waiver (A) releasing the United States of any liability or claim thereof by such tribe or person concerning such remedial action and (B) holding the United States harmless against any claim arising out of the performance of any such remedial action.

(2) The remedial action shall be selected and performed in accordance with section 108 by the Secretary or such person as he may designate.

(3) The Secretary, the Commission, and the Administrator and their authorized representatives shall have a permanent right of entry at any time to inspect such processing site in furtherance of the provisions of this title, to carry out such agreement, and to enforce any rules prescribed under this Act.

Each agreement under this section shall take effect only upon concurrence of the Commission with the terms and conditions thereof.

(b) When the Secretary with the concurrence of the Commission determines removal of residual radioactive materials from a processing site on lands described in subsection (a) to be appropriate, he shall provide, consistent with other applicable provisions of law, a site or sites for the permanent disposition and stabilization in a safe and environmentally sound manner of such residual radioactive materials. Such materials shall be transferred to the Secretary (without payment therefor by the Secretary) and permanently retained and maintained by the Secretary under the conditions established in a license issued by the Commission, subject to section 104(f)(2) and (h).

Transfer to Secretary of the Interior.

ACQUISITION OF LAND BY SECRETARY

42 USC 7916.

SEC. 106. Where necessary or appropriate in order to consolidate in a safe and environmentally sound manner the location of residual radioactive materials which are removed from processing sites under cooperative agreements under this title, or where otherwise necessary for the permanent disposition and stabilization of such materials in such manner—

(1) the Secretary may acquire land and interests in land for such purposes by purchase, donation, or under any other authority of law or

(2) the Secretary of the Interior may make available public lands administered by him for such purposes in accordance with other applicable provisions of law.

Consultation.

Prior to acquisition of land under paragraph (1) or (2) of this subsection in any State, the Secretary shall consult with the Governor of such State. No lands may be acquired under such paragraph (1) or (2) in any State in which there is no (1) processing site designated under this title or (2) active uranium mill operation, unless the Secretary has obtained the consent of the Governor of such State. No lands controlled by any Federal agency may be transferred to the Secretary to carry out the purposes of this Act without the concurrence of the chief administrative officer of such agency.

FINANCIAL ASSISTANCE

42 USC 7917.

SEC. 107. (a) In the case of any designated processing site for which an agreement is executed with any State for remedial action at such site, the Secretary shall pay 90 per centum of the actual cost of such remedial action, including the actual costs of acquiring such site (and any interest therein) or any disposition site (and any interest therein) pursuant to section 108 of this title, and the State shall pay the remainder of such costs from non-Federal funds. The Secretary shall not pay the administrative costs incurred by any State to develop, prepare, and carry out any cooperative agreement executed with such State under this title, except the proportionate share of the administrative costs associated with the acquisition of lands and interests therein acquired by the State pursuant to this title.

(b) In the case of any designated processing site located on Indian lands, the Secretary shall pay the entire cost of such remedial action.

REMEDIAL ACTION

42 USC 7918.

SEC. 108. (a)(1) The Secretary or such person as he may designate shall select and perform remedial actions at designated processing sites and disposal sites in accordance with the general standards prescribed

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by the Administrator pursuant to section 275 a. of the Atomic Energy Act of 1954. The State shall participate fully in the selection and performance of a remedial action for which it pays part of the cost. Such remedial action shall be selected and performed with the concurrence of the Commission and in consultation, as appropriate, with the Indian tribe and the Secretary of the Interior.

(2) The Secretary shall use technology in performing such remedial action as will insure compliance with the general standards promulgated by the Administrator under section 275 a. of the Atomic Energy Act of 1954 and will assure the safe and environmentally sound stabilization of residual radioactive materials, consistent with existing law. No such remedial action may be undertaken under this section before the promulgation by the Administrator of such standards.

Evaluation.

(b) Prior to undertaking any remedial action at a designated site pursuant to this title, the Secretary shall request expressions of interest from private parties regarding the remilling of the residual radioactive materials at the site and, upon receipt of any expression of interest, the Secretary shall evaluate among other things the mineral concentration of the residual radioactive materials at each designated processing site to determine whether, as a part of any remedial action program, recovery of such minerals is practicable. The Secretary, with the concurrence of the Commission, may permit the recovery of such minerals, under such terms and conditions as he may prescribe to carry out the purposes of this title. No such recovery shall be permitted unless such recovery is consistent with remedial action. Any person permitted by the Secretary to recover such mineral shall pay to the Secretary a share of the net profits derived from such recovery, as determined by the Secretary. Such share shall not exceed the total amount paid by the Secretary for carrying out remedial action at such designated site. After payment of such share to the United States under this subsection, such person shall pay to the State in which the residual radioactive materials are located a share of the net profits derived from such recovery, as determined by the Secretary. The person recovering such minerals shall bear all costs of such recovery. Any person carrying out mineral recovery activities under this paragraph shall be required to obtain any necessary license under the Atomic Energy Act of 1954 or under State law as permitted under section 274 of such Act. 42 USC 2021.

RULES

42 USC 7919.

SEC. 109. The Secretary may prescribe such rules consistent with the purposes of this Act as he deems appropriate pursuant to title V of the Department of Energy Organization Act.

ENFORCEMENT

42 USC 7920.

SEC. 110. (a)(1) Any person who violates any provision of this title or any cooperative agreement entered into pursuant to this title or any rule prescribed under this Act concerning any designated processing site, disposition site, or remedial action shall be subject to an assessment by the Secretary of a civil penalty of not more than $1,000 per day per violation. Such assessment shall be made by order after notice and an opportunity for a public hearing, pursuant to section 554 of title 5, United States Code.

Notice, hearing opportunity.

(2) Any person against whom a penalty is assessed under this section may, within sixty calendar days after the date of the order of

the Secretary assessing such penalty, institute an action in the United States court of appeals for the appropriate judicial circuit for judicial review of such order in accordance with chapter 7 of title 5, United States Code. The court shall have jurisdiction to enter a judgment affirming, modifying, or setting aside in whole or in part, the order of the Secretary, or the court may remand the proceeding to the Secretary for such further action as the court may direct.

5 USC 500 *et seq.*
Jurisdiction.

(3) If any person fails to pay an assessment of a civil penalty after it has become a final and unappealable order, the Secretary shall institute an action to recover the amount of such penalty in any appropriate district court of the United States. In such action, the validity and appropriateness of such final assessment order or judgment shall not be subject to review. Section 402(d) of the Department of Energy Organization Act shall not apply with respect to the functions of the Secretary under this section. 42 USC 7172.

(4) No civil penalty may be assessed against the United States or any State or political subdivision of a State or any official or employee of the foregoing.

(5) Nothing in this section shall prevent the Secretary from enforcing any provision of this title or any cooperative agreement or any such rule by injunction or other equitable remedy.

(b) Subsection (a) shall not apply to any licensing requirement under the Atomic Energy Act of 1954. Such licensing requirements shall be enforced by the Commission as provided in such Act. 42 USC 2011 note.

PUBLIC PARTICIPATION

42 USC 7921. Sec. 111. In carrying out the provisions of this title, including the designation of processing sites, establishing priorities for such sites, the selection of remedial actions, and the execution of cooperative agreements, the Secretary, the Administrator, and the Commission shall encourage public participation and, where appropriate, the Secretary shall hold public hearings relative to such matters in the States where processing sites and disposal sites are located.

TERMINATION; AUTHORIZATION

42 USC 7922. Sec. 112. (a) The authority of the Secretary to perform remedial action under this title shall terminate on the date seven years after the date of promulgation by the Administrator of general standards applicable to such remedial action unless such termination date is specifically extended by an Act of Congress enacted after the date of enactment of this Act.

(b) The amounts authorized to be appropriated to carry out the purposes of this title by the Secretary, the Administrator, the Commission, and the Secretary of the Interior shall not exceed such amounts as are established in annual authorization Acts for fiscal year 1979 and each fiscal year thereafter applicable to the Department of Energy. Any sums appropriated for the purposes of this title shall be available until expended.

LIMITATION

42 USC 7923. Sec. 113. The authority under this title to enter into contracts or other obligations requiring the United States to make outlays may

be exercised only to the extent provided in advance in annual authorization and appropriation Acts.

REPORTS TO CONGRESS

42 USC 7924. Sec. 114. (a) Beginning on January 1, 1980, and each year thereafter until January 1, 1986, the Secretary shall submit a report to the Congress with respect to the status of the actions required to be taken by the Secretary, the Commission, the Secretary of the Interior, the Administrator, and the States and Indian tribes under this Act and any amendments to other laws made by this Act. Each report shall—

(1) include data on the actual and estimated costs of the program authorized by this title;

(2) describe the extent of participation by the States and Indian tribes in this program;

(3) evaluate the effectiveness of remedial actions, and describe any problems associated with the performance of such actions; and

(4) contain such other information as may be appropriate.

Such report shall be prepared in consultation with the Commission, the Secretary of the Interior, and the Administrator and shall contain their separate views, comments, and recommendations, if any. The Commission shall submit to the Secretary and Congress such portion of the report under this subsection as relates to the authorities of the Commission under title II of this Act.

(b) Not later than July 1, 1979, the Secretary shall provide a report to the Congress which identifies all sites located on public or acquired lands of the United States containing residual radioactive materials and other reidoactive waste (other than waste resulting from the production of electric energy) and specifies which Federal agency has jurisdiction over such sites. The report shall include the identity of property and other structures in the vicinity of such site that are contaminated or may be contaminated by such materials and the actions planned or taken to remove such materials. The report shall describe in what manner such sites are adequately stabilized and otherwise controlled to prevent radon diffusion from such sites into the environment and other environmental harm. If any site is not so stabilized or controlled, the report shall describe the remedial actions planned for such site and the time frame for performing such actions. In preparing the reports under this section, the Secretary shall avoid duplication of previous or ongoing studies and shall utilize all information available from other departments and agencies of the United States respecting the subject matter of such report. Such agencies shall cooperate with the Secretary in the preparation of such report and furnish such information as available to them and necessary for such report.

Cooperation.

(c) Not later than January 1, 1980, the Administrator, in consultation with the Commission, shall provide a report to the Congress which identifies the location and potential health, safety, and environmental hazards of uranium mine wastes together with recommendations, if any, for a program to eliminate these hazards.

(d) Copies of the reports required by this section to be submitted to the Congress shall be separately submitted to the Committees on Interior and Insular Affairs and on Interstate and Foreign Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate.

(e) The Commission, in cooperation with the Secretary, shall ensure that any relevant information, other than trade secrets and other proprietary information otherwise exempted from mandatory disclosure under any other provision of law, obtained from the conduct of each of the remedial actions authorized by this title and the subsequent perpetual care of those residual radioactive materials is documented systematically, and made publicly available conveniently for use.

ACTIVE OPERATIONS; LIABILITY FOR REMEDIAL ACTION

Sec. 115. (a) No amount may be expended under this title with respect to any site licensed by the Commission under the Atomic Energy Act of 1954 or by a State as permitted under section 274 of such Act at which production of any uranium product from ores (other than from residual radioactive materials) takes place. 42 USC 7925. 42 USC 2011 note. 42 USC 2021.

(b) In the case of each processing site designated under this title, the Attorney General shall conduct a study to determine the identity and legal responsibility which any person (other than the United States, a State, or Indian tribe) who owned or operated or controlled (as determined by the Attorney General) such site before the date of the enactment of this Act may have under any law or rule of law for reclamation or other remedial action with respect to such site. The Attorney General shall publish the results of such study, and provide copies thereof to the Congress, as promptly as practicable following the date of the enactment of this Act. The Attorney General, based on such study, shall, to the extent he deems it appropriate and in the public interest, take such action under any provision of law in effect when uranium was produced at such site to require payment by such person of all or any part of the costs incurred by the United States for such remedial action for which he determines such person is liable. Study.

TITLE II—URANIUM MILL TAILINGS LICENSING AND REGULATION DEFINITION

Sec. 201. Section 11e. of the Atomic Energy Act of 1954, is amended to read as follows: 42 USC 2014.

"e. The term 'byproduct material' means (1) any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material, and (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content." "Byproduct material."

CUSTODY OF DISPOSAL SITES

Sec. 202. (a) Chapter 8 of the Atomic Energy Act of 1954, is amended by adding the following new section at the end thereof: 42 USC 2111 et seq.

"Sec. 83. Ownership and Custody of Certain Byproduct Material and Disposal Sites.— 42 USC 2113.

"a. Any license issued or renewed after the effective date of this section under section 62 or section 81 for any activity which results in the production of any byproduct material, as defined in section 11e. 42 USC 2092, 2111. 42 USC 2014.

(2), shall contain such terms and conditions as the Commission determines to be necessary to assure that, prior to termination of such license—

"(1) the licensee will comply with decontamination, decommissioning, and reclamation standards prescribed by the Commission for sites (A) at which ores were processed primarily for their source material content and (B) at which such byproduct material is deposited, and

"(2) ownership of any byproduct material, as defined in section 11 e. (2), which resulted from such licensed activity shall be transferred to (A) the United States or (B) in the State in which such activity occurred if such State exercises the option under subsection b. (1) to acquire land used for the disposal of byproduct material. 42 USC 2014.

Any license in effect on the date of the enactment of this section shall either contain such terms and conditions on renewal thereof after the effective date of this section, or comply with paragraphs (1) and (2) upon the termination of such license, whichever first occurs.

Rule, regulation or order. "(b) (1) (A) The Commission shall require by rule, regulation, or order that prior to the termination of any license which is issued after the effective date of this section, title to the land, including any interests therein (other than land owned by the United States or by a State) which is used for the disposal of any byproduct material, as defined by section 11 e. (2), pursuant to such license shall be transferred to—

"(A) the United States, or

"(B) the State in which such land is located, at the option of such State.

"(2) Unless the Commission determines prior to such termination that transfer of title to such land and such byproduct material is not necessary or desirable to protect the public health, safety, or welfare or to minimize or eliminate danger to life or property. Such determination shall be made in accordance with section 181 of this Act. Notwithstanding any other provision of law or any such determination, such property and materials shall be maintained pursuant to a license issued by the Commission pursuant to section 84(b) in such manner as will protect the public health, safety, and the environment.

"(B) If the Commission determines by order that use of the surface or subsurface estates, or both, of the land transferred to the United States or to a State under subparagraph (A) would not endanger the public health, safety, welfare, or environment, the Commission, pursuant to such regulations as it may prescribe, shall permit the use of the surface or subsurface estates, or both, of such land in a manner consistent with the provisions of this section. If the Commission permits such use of such land, it shall provide the person who transferred such land with the right of first refusal with respect to such use of such land.

"(2) If transfer to the United States of title to such byproduct material and such land is required under this section, the Secretary of Energy or any Federal agency designated by the President shall, following the Commission's determination of compliance under subsection c., assume title and custody of such byproduct material and land transferred as provided in this subsection. Such Secretary or Federal agency shall maintain such material and land in such manner as will protect the public health and safety and the environment. Such custody may be transferred to another officer or instrumentality of the United States only upon approval of the President.

"(3) If transfer to a State of title to such byproduct material is required in accordance with this subsection, such State shall, following the Commission's determination of compliance under subsection d., assume title and custody of such byproduct material and land transferred as provided in this subsection. Such State shall maintain such material and land in such manner as will protect the public health, safety, and the environment.

42 USC 2092.

"(4) In the case of any such license under section 62, which was in effect on the effective date of this section, the Commission may require, before the termination of such license, such transfer of land and interests therein (as described in paragraph (1) of this subsection) to the United States or a State in which such land is located, at the option of such State, as may be necessary to protect the public health, welfare, and the environment from any effects associated with such byproduct material. In exercising the authority of this paragraph, the Commission shall take into consideration the status of the ownership of such land and interests therein and the ability of the licensee to transfer title and custody thereof to the United States or a State.

Post, p. 3039.

"(5) The Commission may, pursuant to a license, or by rule or order, require the Secretary or other Federal agency or State having custody of such property and materials to undertake such monitoring, maintenance, and emergency measures as are necessary to protect the public health and safety and such other actions as the Commission deems necessary to comply with the standards promulgated pursuant to section 84 of this Act. The Secretary or such other Federal agency is authorized to carry out maintenance, monitoring, and emergency measures, but shall take no other action pursuant to such license, rule or order, with respect to such property and materials unless expressly authorized by Congress after the date of enactment of this Act.

42 USC 2014.

"(6) The transfer of title to land or byproduct materials, as defined in section 11 e. (2), to a State or the United States pursuant to this subsection shall not relieve any licensee of liability for any fraudulent or negligent acts done prior to such transfer.

"(7) Material and land transferred to the United States or a State in accordance with this subsection shall be transferred without cost to the United States or a State (other than administrative and legal costs incurred in carrying out such transfer). Subject to the provisions of paragraph (1)(B) of this subsection, the United States or a State shall not transfer title to material or property acquired under this subsection to any person, unless such transfer is in the same manner as provided under section 104(h) of the Uranium Mill Tailings Radiation Control Act of 1978.

"(8) The provisions of this subsection respecting transfer of title and custody to land shall not apply in the case of lands held in trust by the United States for any Indian tribe or lands owned by such Indian tribe subject to a restriction against alienation imposed by the United States. In the case of such lands which are used for the disposal of byproduct material, as defined in section 11 e. (2), the licensee shall be required to enter into such arrangements with the Commission as may be appropriate to assure the long-term maintenance and monitoring of such lands by the United States.

"c. Upon termination on any license to which this section applies, the Commission shall determine whether or not the licensee has complied with all applicable standards and requirements under such license.".

Effective date.
42 USC 2113 note.

(b) This section shall be effective three years after the enactment of this Act.

(c) The table of contents for chapter 8 of the Atomic Energy Act of 1954, is amended by inserting the following new item after the item relating to section 82:

"Sec. 83. Ownership and custody of certain byproduct material and disposal sites.".

AUTHORITY TO ESTABLISH CERTAIN REQUIREMENTS

42 USC 2201.

SEC. 203. Section 161 of the Atomic Energy Act of 1954, is amended by adding the following new subsection at the end thereof:

42 USC 2231.

"x. Establish by rule, regulation, or order, after public notice, and in accordance with the requirements of section 181 of this Act, such standards and instructions as the Commission may deem necessary or desirable to ensure—

42 USC 2014.

"(1) that an adequate bond, surety, or other financial arrangement (as determined by the Commission) will be provided, before termination of any license for byproduct material as defined in section 11 e. (2), by a licensee to permit the completion of all requirements established by the Commission for the decontamination, decommissioning, and reclamation of sites, structures, and equipment used in conjunction with byproduct material as so defined, and

"(2) that—

"(A) in the case of any such license issued or renewed after the date of the enactment of this subsection, the need for long term maintenance and monitoring of such sites, structures and equipment after termination of such license will be minimized and, to the maximum extent practicable, eliminated; and

"(B) in the case of each license for such material (whether in effect on the date of the enactment of this section or issued or renewed thereafter), if the Commission determines that any such long-term maintenance and monitoring is necessary, the licensee, before termination of any license for byproduct material as defined in section 11 e. (2), will make available such bonding, surety, or other financial arrangements as may be necessary to assure such long-term maintenance and monitoring.

Such standards and instructions promulgated by the Commission pursuant to this subsection shall take into account, as determined by the Commission, so as to avoid unnecessary duplication and expense, performance bonds or other financial arrangements which are required by other Federal agencies or State agencies and/or other local governing bodies for such decommissioning, decontamination, and reclamation and long-term maintenance and monitoring except that nothing in this paragraph shall be construed to require that the Commission accept such bonds or arrangements if the Commission determines that such bonds or arrangements are not adequate to carry out subparagraphs (1) and (2) of this subsection.".

COOPERATION WITH STATES

42 USC 2021.

SEC. 204. (a) Section 274 b. of the Atomic Energy Act of 1954, is amended by adding "as defined in section 11 e. (1)" after the words "byproduct materials" in paragraph (1) by renumbering paragraphs (2) and (3) as paragraphs (3) and (4); and by inserting the following new paragraph immediately after paragraph (1):

"(2) byproduct materials as defined in section 11 e. (2);".

42 USC 2021.

(b) Section 274 d. (2) of such Act is amended by inserting the following before the word "compatible": "in accordance with the requirements of subsection o. and in all other respects".

"Agreement."

(c) Section 274 n. of such Act is amended by adding the following new sentence at the end thereof: "As used in this section, the term 'agreement' includes any amendment to any agreement.".

(d) Section 274 j. of such Act is amended—

(1) by inserting "all or part of" after "suspend";

(2) by inserting "(1)" after "finds that"; and

Review.

(3) by adding at the end before the period the following: ", or (2) the State has not complied with one or more of the requirements of this section. The Commission shall periodically review such agreements and actions taken by the States under the agreements to ensure compliance with the provisions of this section.".

(e) (1) Section 274 of such Act is amended by adding the following new subsection at the end thereof:

"o. In the licensing and regulation of byproduct material, as defined in section 11 e. (2) of this Act, or of any activity which results in the production of byproduct material as so defined under an agreement entered into pursuant to subsection b., a State shall require—

"(1) compliance with the requirements of subsection b. of section 83 (respecting ownership of byproduct material and land), and

Ante, p. 3033.
Post, p. 3039.

"(2) compliance with standards which shall be adopted by the State for the protection of the public health, safety, and the environment from hazards associated with such material which are equivalent, to the extent practicable, or more stringent than, standards adopted and enforced by the Commission for the same purpose, including requirements and standards promulgated by the Commission and the Administrator of the Environmental Protection Agency pursuant to sections 83, 84, and 275, and

"(3) procedures which—

"(A) in the case of licenses, provide procedures under State law which include—

"(i) an opportunity, after public notice, for written comments and a public hearing, with a transcript,

"(ii) an opportunity for cross examination, and

"(iii) a written determination which is based upon findings included in such determination and upon the evidence presented during the public comment period and which is subject to judicial review;

"(B) in the case of rulemaking, provide an opportunity for public participation through written comments or a public hearing and provide for judicial review of the rule;

"(C) require for each license which has a significant impact on the human environment a written analysis (which shall be available to the public before the commencement of any such proceedings) of the impact of such license, including any activities conducted pursuant thereto, on the environment, which analysis shall include—

"(i) an assessment of the radiological and nonradiological impacts to the public health of the activities to be conducted pursuant to such license;

"(ii) an assessment of any impact on any waterway and groundwater resulting from such activities;

"(iii) consideration of alternatives, including alternative sites and engineering methods, to the activities to be conducted pursuant to such license; and

"(iv) consideration of the long-term impacts, including decommissioning, decontamination, and reclamation impacts, associated with activities to be conducted pursuant to such license, including the management of any byproduct material, as defined by section 11 e. (2); and

"(D) prohibit any major construction activity with respect to such material prior to complying with the provisions of subparagraph (C).

Ante, p. 3033.
42 USC 2201.

If any State under such agreement imposes upon any licensee any requirement for the payment of funds to such State for the reclamation or long-term maintenance and monitoring of such material, and if transfer to the United States of such material is required in accordance with section 83 b. of this Act, such agreement shall be amended by the Commission to provide that such State shall transfer to the United States upon termination of the license issued to such licensee the total amount collected by such State from such licensee for such purpose. If such payments are required, they must be sufficient to ensure compliance with the standards established by the Commission pursuant to section 161 x. of this Act. No State shall be required under paragraph (3) to conduct proceedings concerning any license or regulation which would duplicate proceedings conducted by the Commission.".

42 USC 2021.

(f) Section 274 c. of such Act is amended by inserting the following new sentence after paragraph (4) thereof: "The Commission shall also retain authority under any such agreement to make a determination that all applicable standards and requirements have been met prior to termination of a license for byproduct material, as defined in section 11 e. (2).".

42 USC 2014.
42 USC 2021 note.

(g) Nothing in any amendment made by this section shall preclude any State from exercising any other authority as permitted under the Atomic Energy Act of 1954 respecting any byproduct material, as defined in section 11 e. (2) of the Atomic Energy Act of 1954.

42 USC 2021 note.

(h) (1) On or before the date three years after the date of the enactment of this Act, notwithstanding any amendment made by this title, any State may exercise any authority under State law respecting byproduct material, as defined in section 11 e. (2) of the Atomic Energy Act of 1954, in the same manner, and to the same extent, as permitted before the enactment of this Act.

(2) An agreement entered into with any State as permitted under section 274 of the Atomic Energy Act of 1954 with respect to byproduct material as defined in section 11 e. (2) of such Act, may be entered into at any time after the date of the enactment of this Act but no such agreement may take effect before the date three years after the date of the enactment of this Act.

AUTHORITIES OF COMMISSION RESPECTING CERTAIN BYPRODUCT MATERIAL

42 USC 2111 *et seq.*

SEC. 205. (a) Chapter 8 of the Atomic Energy Act of 1954, is amended by adding the following new section at the end thereof:

42 USC 2114.

"SEC. 84. AUTHORITIES OF COMMISSION RESPECTING CERTAIN BYPRODUCT MATERIAL.—

42 USC 2014.

"a. The Commission shall insure that the management of any byproduct material, as defined in section 11 e. (2), is carried out in such manner as—

"(1) the Commission deems appropriate to protect the public health and safety and the environment from radiological and nonradiological hazards associated with the processing and with the possession and transfer of such material,

Infra.

"(2) conforms with applicable general standards promulgated by the Administrator of the Environmental Protection Agency under section 275, and

42 USC 6901 note.

"(3) conforms to general requirements established by the Commission, with the concurrence of the Administrator, which are, to the maximum extent practicable, at least comparable to requirements applicable to the possession, transfer, and disposal of similar hazardous material regulated by the Administrator under the Solid Waste Disposal Act, as amended.

Rule, regulation or order.

"b. In carrying out its authority under this section, the Commission is authorized to—

42 USC 2111.

"(1) by rule, regulation, or order require persons, officers, or instrumentalities exempted from licensing under section 81 of this Act to conduct monitoring, perform remedial work, and to comply with such other measures as it may deem necessary or desirable to protect health or to minimize danger to life or property, and in connection with the disposal or storage of such byproduct material; and

"(2) make such studies and inspections and to conduct such monitoring as may be necessary.

Civil penalty.

Ante, p. 3033.

42 USC 2282.

Any violation by any person other than the United States or any officer or employee of the United States or a State of any rule, regulation, or order or licensing provision, of the Commission established under this section or section 83 shall be subject to a civil penalty in the same manner and in the same amount as violations subject to a civil penalty under section 234. Nothing in this section affects any authority of the Commission under any other provision of this Act.".

42 USC 2111.

42 USC 2112.

(b) The first sentence of section 81 of the Atomic Energy Act of 1954, is amended to read as follows: "No person may transfer or receive in interstate commerce, manufacture, produce, transfer, acquire, own, possess, import, or export any byproduct material, except to the extent authorized by this section, section 82 or section 84.".

Supra.

(c) The table of contents for such chapter 8 is amended by inserting the following new item after the item relating to section 83:

"Sec. 84. Authorities of Commission respecting certain byproduct material.".

AUTHORITY OF ENVIRONMENTAL PROTECTION AGENCY RESPECTING CERTAIN BYPRODUCT MATERIAL

42 USC 2021.

SEC. 206. (a) Chapter 19 of the Atomic Energy Act of 1954, is amended by inserting after section 274 the following new section:

42 USC 2022.

"SEC. 275. HEALTH AND ENVIRONMENTAL STANDARDS FOR URANIUM MILL TAILINGS.—

Rule.

"a. As soon as practicable, but not later than one year after the date of enactment of this section, the Administrator of the Environmental Protection Agency (hereinafter referred to in this section as the 'Administrator') shall, by rule, promulgate standards of general application (including standards applicable to licenses under section 104(h) of the Uranium Mill Tailings Radiation Control Act of 1978) for the protection of the public health, safety, and the environment from radiological and nonradiological hazards associated with residual radioactive materials (as defined in section 101 of the Uranium Mill Tailings Radiation Control Act of 1978) located at inactive uranium mill tailings sites and depository sites for such materials selected by the Secretary of Energy, pursuant to title I of the Uranium Mill Tailings Radiation Control Act of 1978. Standards promulgated pursuant to this subsection shall, to the maximum extent practicable, be consistent with the requirements of the Solid Waste Disposal Act, as amended. The Administrator may periodically revise any standard promulgated pursuant to this subsection.

42 USC 6901 note.

Rule.

42 USC 2014.

"b. (1) As soon as practicable, but not later than eighteen months after the enactment of this section, the Administrator shall, by rule, promulgate standards of general application for the protection of the public health, safety, and the environment from radiological and nonradiological hazards associated with the processing and with the possession, transfer, and disposal of byproduct material, as defined in section 11 e. (2) of this Act, at sites at which ores are processed primarily for their source material content or which are used for the disposal of such byproduct material.

42 USC 2021.

"(2) Such generally applicable standards promulgated pursuant to this subsection for nonradiological hazards shall provide for the protection of human health and the environment consistent with the standards required under subtitle C of the Solid Waste Disposal Act, as amended, which are applicable to such hazards: *Provided, however*, That no permit issued by the Administrator is required under this Act or the Solid Waste Disposal Act, as amended, for the processing, possession, transfer, or disposal of byproduct material, as defined in section 11 e. (2) of this Act. The Administrator may periodically revise any standard promulgated pursuant to this subsection. Within three years after such revision of any such standard, the Commission and any State permitted to exercise authority under section 274 b. (2) shall apply such revised standard in the case of any license for byproduct material as defined in section 11 e. (2) or any revision thereof.

Publication in Federal Register.
Notice, hearing opportunity.

Consultation.

"c. (1) Before the promulgation of any rule pursuant to this section, the Administrator shall publish the proposed rule in the Federal Register, together with a statement of the research, analysis, and other available information in support of such proposed rule, and provide a period of public comment of at least thirty days for written comments thereon and an opportunity, after such comment period and after public notice, for any interested person to present oral data, views, and arguments at a public hearing. There shall be a transcript of any such hearing. The Administrator shall consult with the Commission and the Secretary of Energy before promulgation of any such rule.

Judicial review.

"(2) Judicial review of any rule promulgated under this section may be obtained by any interested person only upon such person filing a petition for review within sixty days after such promulgation in the United States court of appeals for the Federal judicial circuit in which such person resides or has his principal place of business. A copy of the petition shall be forthwith transmitted by the clerk of court to the Administrator. The Administrator thereupon shall file in the court the written submissions to, and transcript of, the written or oral proceedings on which such rule was based as provided in section 2112 of title 28, United States Code. The court shall have jurisdiction to review the rule in accordance with chapter 7 of title 5, United States Code, and to grant appropriate relief as provided in such chapter. The judgment of the court affirming, modifying, or setting aside, in whole or in part, any such rule shall be final, subject to judicial review by the Supreme Court of the United States upon certiorari or certification as provided in section 1254 of title 28, United States Code.

5 USC 701 *et seq.*

"(3) Any rule promulgated under this section shall not take effect earlier than sixty calendar days after such promulgation.

"d. Implementation and enforcement of the standards promulgated pursuant to subsection b. of this section shall be the responsibility of the Commission in the conduct of its licensing activities under this Act. States exercising authority pursuant to section 274 b. (2) of this Act shall implement and enforce such standards in accordance with subsection c. of such section.

42 USC 2021.

"e. Nothing in this Act applicable to byproduct material, as defined in section 11 e. (2) of this Act, shall affect the authority of the Administrator under the Clean Air Act of 1970, as amended, or the Federal Water Pollution Control Act, as amended.".

42 USC 2014.
42 USC 7401 note.
33 USC 1251 note.

(b) The table of contents for chapter 19 of the Atomic Energy Act is amended by inserting the following new item after the item relating to section 274:

42 USC 2018 *et seq.*

"Sec. 275. Health and environmental standards for uranium mill tailings.".

AUTHORIZATION OF APPROPRIATION FOR GRANTS

SEC. 207. There is hereby authorized to be appropriated for fiscal year 1980 to the Nuclear Regulatory Commission not to exceed $500,000 to be used for making grants to States which have entered into agreements with the Commission under section 274 of the Atomic Energy Act of 1954, to aid in the development of State regulatory programs under such section which implement the provisions of this Act.

EFFECTIVE DATE

SEC. 208. Except as otherwise provided in this title the amendments made by this title shall take effect on the date of the enactment of this Act.

42 USC 2014 note.

CONSOLIDATION OF LICENSES AND PROCEDURES

SEC. 209. The Nuclear Regulatory Commission shall consolidate, to the maximum extent practicable, licenses and licensing procedures under amendments made by this title with licenses and licensing procedures under other authorities contained in the Atomic Energy Act of 1954.

42 USC 2113 note.
42 USC 2011 note.

TITLE III—STUDY AND DESIGNATION OF TWO MILL TAILINGS SITES IN NEW MEXICO

STUDY

42 USC 7941.

SEC. 301. The Commission, in consultation with the Attorney General and the Attorney General of the State of New Mexico, shall conduct a study to determine the extent and adequacy of the authority of the Commission and the State of New Mexico to require, under the Atomic Energy Act of 1954 (as amended by title II of this Act) or under State authority as permitted under section 274 of such Act or under other provision of law, the owners of the following active uranium mill sites to undertake appropriate action to regulate and control all residual radioactive materials at such sites to protect public health, safety, and the environment: the former Homestake-New Mexico Partners site near Milan, New Mexico, and the Anaconda carbonate process tailings site near Bluewater, New Mexico. Such study shall be completed and a report thereof submitted to the Congress and to the Secretary within one year after enactment of this Act, together with such recommendations as may be appropriate. If the Commission determines that such authority is not adequate to regulate and control such materials at such sites in the manner provided in the first sentence of this section, the Commission shall include in the report a statement of the basis for such determination. Nothing in this Act shall be construed to prevent or delay action by a State as permitted under section 274 of the Atomic Energy Act of 1954 or under any other provision of law or by the Commission to regulate such residual radioactive materials at such sites prior to completion of such study.

42 USC 2021.

Report to Congress.

DESIGNATION BY SECRETARY

42 USC 7942.

SEC. 302. (a) Within ninety days from the date of his receipt of the report and recommendations submitted by the Commission under section 301, notwithstanding the limitations contained in section 101(6)(A) and in section 115(a), if the Commission determines, based on such study, that such sites cannot be regulated and controlled by the State or the Commission in the manner described in section 301, the Secretary may designate either or both of the sites referred to in section 301 as a processing site for purposes of title I. Following such designation, the Secretary may enter into cooperative agreements with New Mexico to perform remedial action pursuant to such title concerning only the residual radioactive materials at such site resulting from uranium produced for sale to a Federal agency prior to January 1, 1971, under contract with such agency. Any such designation shall be submitted by the Secretary, together with his estimate of the cost of carrying out such remedial action at the designated site, to the Committee on Interior and Insular Affairs and the Committee on Interstate and Foreign Commerce of the House of Representatives and to the Committee on Energy and Natural Resources of the Senate.

Submittal to congressional committees.

(b)(1) No designation under subsection (a) shall take effect before the expiration of one hundred and twenty calendar days (not including any day in which either House of Congress is not in session because of an adjournment of more than three calendar days to a day certain or an adjournment sine die) after receipt by such Committees of such designation.

(c) Except as otherwise specifically provided in subsection (a), any remedial action under title I with respect to any sites designated under this title shall be subject to the provisions of title I (including the authorization of appropriations referred to in section 112(b)).

Approved November 8, 1978.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 95-1480, Pt. I (Comm. on Interior and Insular Affairs) and Pt. II (Comm. on Interstate and Foreign Commerce).
CONGRESSIONAL RECORD, Vol. 124 (1978):
Oct. 3, considered and passed House.
Oct. 13, considered and passed Senate, amended.
Oct. 14, House concurred in Senate amendment with amendments.
Oct. 15, Senate concurred in House amendment.

Public Law 96-106
96th Congress

An Act

Nov. 9, 1979
[H.R. 4249]

To amend title 23 of the United States Code, the Surface Transportation Assistance Act of 1978, and for other purposes.

*****

92 Stat. 306.
42 USC 2021 note.

SEC. 22. (a) Section 204(h) of the Uranium Mill Tailings Radiation Control Act of 1978 is amended by adding at the end thereof the following new paragraph:

42 USC 2021.
92 Stat. 3033.
42 USC 2014.

"(3) Notwithstanding any other provision of this title, where a State assumes or has assumed, pursuant to an agreement entered into under section 274 b. of the Atomic Energy Act of 1954, authority over any activity which results in the production of byproduct material, as defined in section 11 e. (2) of such Act, the Commission shall not, until the end of the three-year period beginning on the date of the enactment of this Act, have licensing authority over such byproduct material produced in any activity covered by such agreement, unless the agreement is terminated, suspended, or amended to provide for such Federal licensing. If, at the end of such three-year period, a State has not entered into such an agreement with respect to byproduct material, as defined in section 11 e. (2) of the Atomic Energy Act of 1954, the Commission shall have authority over such byproduct material.".

(b) Section 204(h)(1) of the Uranium Mill Tailings Radiation Control Act of 1978 is amended to read as follows:

42 USC 2021.
92 Stat. 3033.
42 USC 2014.
92 Stat. 3036.
42 USC 2021.
92 Stat. 3039.
42 USC 2022.

"(h)(1) During the three-year period beginning on the date of the enactment of this Act, notwithstanding any other provision of this title, any State may exercise any authority under State law (including authority exercised pursuant to an agreement entered into pursuant to section 274 of the Atomic Energy Act of 1954) respecting (A) byproduct material, as defined in section 11 e. (2) of the Atomic Energy Act of 1954, or (B) any activity which results in the production of byproduct material as so defined, in the same manner and to the same extent as permitted before the date of the enactment of this Act, except that such State authority shall be exercised in a manner which, to the extent practicable, is consistent with the requirements of section 274 o. of the Atomic Energy Act of 1954 (as added by section 204(e) of this Act). The Commission shall have the authority to ensure that such section 274 o. is implemented by any such State to the extent practicable during the three-year period beginning on the date of the enactment of this Act. Nothing in this section shall be construed to preclude the Commission or the Administrator of the Environmental Protection Agency from taking such action under section 275 of the Atomic Energy Act of 1954 as may be necessary to implement title I of this Act.".

42 USC 7911.
92 Stat. 3032.
42 USC 2113.

(c) The last sentence of section 83 a. of the Atomic Energy Act of 1954 is amended to read as follows: "Any license which is in effect on the effective date of this section and which is subsequently terminated without renewal shall comply with paragraphs (1) and (2) upon termination.".

92 Stat. 3037.
42 USC 2021 note.

(d) Section 204(e) of the Uranium Mill Tailings Radiation Control Act of 1978 is amended by adding after paragraph (1) the following new paragraph:

"(2) The provisions of the amendment made by paragraph (1) of this subsection (which adds a new subsection o. to section 274 of the Atomic Energy Act of 1954) shall apply only to the maximum extent practicable during the three-year period beginning on the date of the enactment of this Act."

92 Stat. 3033.
42 USC 2113.

(e) Section 83(b)(1)(A) of the Atomic Energy Act of 1954 is amended—

(1) by striking all that follows "transferred to—" down through "Unless" and inserting in lieu thereof the following:

"(i) the United States, or

"(ii) the State in which such land is located, at the option of such State,

unless"; and

42 USC 2111.

(2) by striking "section 84 b." and inserting in lieu thereof "section 81 of this Act".

*****

APPENDIX R. COSTS OF POST-OPERATIONAL SITE SURVEILLIANCE

1. INTRODUCTION

Basically, the amount of ongoing effort and spending that will be required over the long term at disposal sites will depend upon the degree to which the tailings are isolated.

This presentation of several scenarios involving different levels of site surveillance and/or maintenance is for illustrative purposes. It points out the potential range of long-term annual costs which might be required for the alternative modes of tailings disposal examined in this study (see Chapter 8) and also serves as a basis for establishing requirements concerning funding of ongoing surveillance activity (Chapter 14, Section 14.3). Five major scenarios are described; these scenarios are consistent with the description of long-term monitoring presented in Section 10.3. For those sites which meet the proposed tailings disposal requirements delineated in Section 12.2 to their fullest extent (most likely in the case of new sites, see Section 12.4), the staff considers the nature and extent of effort involved is described reasonably well by Scenario I and that this scenario provides as reasonable a basis as can be formed for establishing a system of long-term funding in advance of actually carrying out the surveillance. In some limited situations, a small degree of surveillance beyond that postulated in Scenario I might be required. If this is needed, expected additional expenses must be determined on the basis of site-specific conditions. The scenarios described below are intended to provide a reasonable bound on the range of costs which could be incurred, including, for completeness, cases where tailings are disposed of under the active care mode rejected by the staff in Chapter 12 (Section 12.3).

2. SCENARIO I - PASSIVE MONITORING

The primary component of Scenario I is annual visual inspection of each site. This might be accomplished by either site visits or by fly overs including high resolution aerial photography. The purpose of this inspection would be to confirm that no unexpected erosion was occurring and that there were no disruptive human activities at a site. Little or no groundwater monitoring is included in this scenario; therefore, no heavy sampling or monitoring equipment needs to be transported. It is assumed that the inspector could travel to the sites by airplane. Where limited groundwater sampling is performed this could be done with portable equipment. No active care or remedial actions are expected to be required.

Virtually the only cost item for long-term monitoring, therefore, is expected to be the time and effort of government inspectors who will visit the sites--their time in travel, making inspections, and preparing for and following up on inspections. The amount of time required for travel and inspection depends on the location of mill sites, with respect to the home base of inspection and with respect to each other. For example, there will be less travel and inspection time per site in regions where several mills are clustered, since inspections of sites in such areas can be combined. Therefore, to estimate this time, the staff examined the current pattern of mill siting (including inactive sites). About 90 percent of current mill sites are located in clusters within one of five major mining and milling areas. These are near Falls City, Texas (Texas Coastal Region), Grants, New Mexico (Grants Mineral Belt), Grand Junction, Colorado (Uravan Mineral Belt), Casper, Wyoming (ore deposits in Powder River Basin, Shirley Basin, Crooks Gap and Gas Hills regions), and near Spokane, Washington. Remaining sites are located in about a half dozen isolated areas.

The staff estimates that, on the average, it would take about two days travel time to go from any inspection home base in the west to any site, or in the case of mill clusters, to any cluster and return. Further, it is assumed that one-half to one day would be required for actual site inspection, the former likely being a better estimate. Based on these estimates, the mill clustering pattern, and allowing for some delays and disruption because of bad weather, the average time in travel and inspection is from one to two days per site per year. To account for in-office time associated with an inspection, that is, preparing for and doing followup work on inspections, such as preparing reports, it is reasonable to assume that the total amount of time per year devoted to each site would be between three and eight days (2 to 3 days in-office are assumed for each day in the field).

To convert this to a cost estimate, the staff used an annual cost of $65,000 (about $250/day in 1978 dollars) for an inspector. This cost comes from calculations recently made by the NRC staff in connection with establishing licensing fees (42 FR 22149).[1] This is the annual cost for one inspector in the NRC's Office of Inspection and Enforcement. It includes salary, personal benefits, administrative support, travel, management supervision and general overhead. The resulting estimate of costs per site is about $750 to $2,000. The cost estimates are summarized as follows:

- Lower bound:

  1 day (travel and inspection) + 2 days (office) = 3 days
  3 days x $250 = $750

- Upper bound:

  2 days (travel and inspection) + 6 days (office) = 8 days
  8 days x $250 = $2,000

Where limited groundwater sampling is conducted, analysis costs would be incurred. This would be limited to analysis for selected chemical species which because of their mobility would effectively provide an indicator of groundwater problems if they were to occur. Because groundwater movement is very slow in most cases (centimeters per year), confirmatory sampling and analysis could be done on a relatively infrequent basis such as every 2-5 years depending on site conditions. These analysis costs would be on the order of about $100-200. Miscellaneous equipment including cameras and portable groundwater sampling equipment would be nominal in cost when amortized over a period of from 5 to 10 years and over all sites. According to the recent legislation on uranium mill tailings, as described in Chapter 13, NRC will have an oversight role in long-term monitoring of the sites. This will likely be an audit function with DOE (or the appropriate State agency if the State owns the site) having primary responsibility for inspection. It is estimated that costs associated with this effort would be about 10% of those incurred by the inspecting agency. It is conservatively estimated that costs for such analyses and miscellaneous equipment, as well as 10% of the total inspection cost in order to take into account NRC oversight, would total no more than about $500 per year. Therefore, a conservative upper bound estimate of annual costs for Scenario I is about $2,500.

3. SCENARIO II - INSPECTION PLUS GROUNDWATER MONITORING

For Scenario II the primary component again is annual inspections; however, this scenario includes an increased level of groundwater monitoring. While the cost for the inspector's time remains as the major element of the total surveillance costs under Scenario II, equipment costs (including a vehicle for transporting the monitoring equipment) and sample analysis costs increase considerably. Establishment of a groundwater sampling program involving frequent sampling is expected to be required, if at all, at only some sites where particular problems or concerns are identified during the preoperational and operational monitoring periods and during the compliance determination period. (See Section 14.1.)

While it is not expected that it be warranted, an increased level of groundwater monitoring can be postulated for all sites to provide a potential upper bound of site surveillance costs. This scenario assumes that monitoring wells at all sites would be checked using dynamic as opposed to simple static (bailer lowered into monitoring well) samples. More specifically, submersible pumps powered by gasoline generators mounted on four-wheel drive vehicles are postulated for driving between sites to draw samples and perform visual inspections. It is likely that the frequency of this mode of inspection could be reduced considerably by taking most samples using portable bailing equipment (which could be carried by inspectors flying to sites). The results of these static samples would be checked every several years by the more sophisticated dynamic sample taking procedures.

3.1 Inspection

Again, the amount of time required for travel and inspection depends on the location of mill sites, with respect to the home base and with respect to each other. The location of mill sites is assumed to follow the pattern described under Scenario I. If it is assumed that Grand Junction, Colorado is the inspector's home base, the distances to the four other mill clusters are as follow:

Grants, New Mexico	∼350 miles	or 700 miles round trip
Casper, Wyoming	∼500 miles	or 1,000 miles round trip
Spokane, Washington	∼1,000 miles	or 2,000 miles round trip
Falls City, Texas	∼1,500 miles	or 3,000 miles round trip
		6,700 miles

For this scenario, the situation 25-50 years into the future is covered; that is, after a large number of sites have been decommissioned. More specifically, it is assumed that there are 25 decommissioned sites. This figure was somewhat arbitrarily selected. It is expected that only a few sites will be decommissioned between now and the year 2000. Therefore, when this is added to the number of currently inactive sites, the round figure of 25 sites seems reasonable to use for purposes of this analysis.

The location of current peripheral sites indicates that a good estimate of total mileage traveled per year for the 25 sites, a figure which we have somewhat arbitrarily selected as a likely estimate of the total number of decommissioned sites by the year 2000, is double this figure or about 13,000 miles. While this distance is assumed for this illustrative scenario, it is possible that sample taking and inspection could be performed through regional DOE operations, such as at the Richland/Hanford site, in which case costs could be somewhat less.

A more complete description of assumptions for travel and inspection costs under Scenario II are:

- Each site is inspected approximately once a year by the mobile inspectors unit.
- Total time of travel assumed to cover the 25 or so sites =
  13,000 miles ÷ 350 mi/day = 37 days
  This is equivalent to about 1.5 days per site.
- Average time in inspection and sample taking at sites where about 5 wells are sampled - 1 to 2 days.
- Ratio of in-office time to the time in travel and in field - 2:1 to 3:1.
- Two persons would go to sites to do inspection and sampling. These would be senior and junior technicians. ($30,000 to $20,000 for salary and overhead assumed respectively.) Supervision and office followup might be done by a project manager ($50,000 for salary and overhead assumed) in conjunction with the two field workers.

Based on these assumptions, costs for travel and inspection compute as follows:

- Lower bound:

2.5 days (travel and inspection) x 2 inspectors

2.5 x $125 ($30,000 per year)		
+ 2.5 x $ 83 ($20,000 per year)		
2.5 x $208 ~$200	2.5 days x $200 = $500	$500
per diem = $35/day	5 x $35 = $175	$175
travel - $ .17/mile	$ .17 x 13,000 miles = $2,210	$100
$2,210 ÷ 25 = $88 ~$100		
10 days (office) x $200 = $2,000		$2,000
		$2,775/year or ~$3,000/year

Upper bound:

3.5 days (travel and inspection) x 2 inspectors

3.5 x $125		
+ 3.5 x $ 83		
3.5 x $208 ~$200	3.5 days x $200 = $700	$700
per diem = $35/day	7 x $35 = $245	$245
travel - $ .17/mile	$ .17 x 13,000 miles = $2,210	$100
$2,210 ÷ 25 = $88 or ~$100		
21 days (office) x $200 = $4,200		$4,200
		$5,245 or ~5,000/year

3.2 Equipment

Equipment would include the following:

a. Capital Costs

2 submersible pumps (operating pump and spare). Capacity of 6.6 gpm @ 480 feet. Sized to permit very deep well sampling. Unit price - $335	$670
2 generators - (one for spare), 7 hp. units at $580 each.	$1,160
4-wheel drive vehicle with A-frame sampler hoist and power winch.	$12,000
Hose - 500 ft. 1" hose @ $1.50 lineal foot	$750
Total costs for above	$14,580

- Monitoring wells are assumed to be in place from operational monitoring period. Each assumed to be replaced every 50 years, 5 at each site. 4-inch PVC and concrete-cased well with padlocked manhole, $7,000 each[2] 5 x 7000 ÷ 50 years = $700 at each site per year.

b. Annual Capital Costs and Supplies

Assume equipment is amortized over 5 year period - $\frac{\$14,580}{5}$ = $2,916 ~$3,000	$3,000
Maintenance costs and repair supplies. 10% capital costs assumed.	$1,500
Supplies and miscellaneous sampling equipment such as sample bottles, reagents, fuel for generator, etc. covered. (Sampling analysis costs below.)	$4,000
Total costs	$8,500

c. Average Annual Capital Cost per Site

$8,500 ÷ 25 = $340 ~$350	$350
$700 per site for monitoring well replacement	$700
	$1,050 ~$1,000/site

3.3 Sample Analysis

The specific kind of water sample analysis that must be performed will be a function of site specific concerns. During the periods of preoperational and operational monitoring, selected species such as sulfate ion may be identified as effective indicators of potential groundwater problems. Therefore, analysis procedures could be simplified to isolate indicator elements. Assumptions that have been made with respect to sample analysis for this cost estimate are:

- The kinds of analysis and costs outlined on the following table are assumed to bound the situation.
- Five samples are drawn at each site - two upstream and three downstream.
- On the average a fairly comprehensive analysis could be performed for approximately $750 - 1000 per site.

Therefore, the lower and upper bound cost estimates for Scenario II are:

Lower bound:

$3,000 (travel and inspection) + $1,000 (sampling equipment) +
$1,000 (sample analysis) = $5,000

Upper bound:

$5,000 (travel and inspection) + $1,000 (sampling equipment) + $1,000 (sample analysis) = $7,000.

COST OF WATER QUALITY ANALYSES[2]
(1978 Dollars)

Major Inorganic Chemicals

Iron
Magnesium
Chloride
Carbonate
Bicarbonate
Sodium
Potassium
pH
Electrical Conductivity

Group Rate: $53.50 to $107.00

Comprehensive Analysis

Uranium
Vanadium
Copper
Selenium
Molybdenum
Arsenic
Radium 225
Lead
Iron
Manganese
Chromium
Nickel
Cobalt
Cadmium
Mercury
Zinc
Barium
Fluoride
Boron
Magnesium
Chloride
Sulfate
Carbonate
Bicarbonate
Nitrate
Ammonia
Sodium
Calcium
Potassium
Silica
Gross Alpha
Gross Beta
Total Dissolved Solids
pH
Electrical Conductivity

Group Rate: $206.00 to $447.00

Gross Alpha
Gross Beta
Radium 226
Uranium

Group Rate: $41.00 to $94.00

4. SCENARIO III - PASSIVE MONITORING PLUS FENCING

It may be determined at some sites that maintaining a fence around the tailings disposal area provides a necessary added measure of protection and isolation. For example, it can be postulated that a fence would be required to restrict grazing if grazing pressures are great or prevent other animal disturbance. In all probability fencing would only be necessary in relatively populated areas or areas where grazing pressures warrant this.

In any event, if it were determined that fencing was required at a certain site, it can be assumed that the initial cost of installing the fence would be included in the reclamation costs. However, costs for repair and/or replacement of the fence should be covered in the cost estimates for long-term surveillance.

It is assumed that a very heavy duty fence would be installed (6 gage wire). The cost estimates on this type of fence range from $6.50 to $10.00 per lineal foot. For purposes of this cost estimate $8.50/LF has been chosen as the average unit cost. Total costs would depend upon the size of the disposal area. However, to illustrate these costs the disposal area is assumed to be approximately 1,000 meters (13,200 ft.) on each side. At $8.50/LF the cost of replacing the entire fence would be $112,200. Assuming that the fence will last approximately 100 years and the cost of replacing the fence can be amortized over this period, the annual fencing cost is $1,122 or approximately $1,000.

Therefore, if for illustrative purposes we add this cost for fencing to the upper bound cost estimates for Scenarios I and II, the total costs for passive monitoring plus fencing are:

$2,500 (Scenario I inspection) + $1,000 (fencing) = $3,500
$7,000 (Scenario II inspection, sampling & analysis) + $1,000 (fencing) $8,000

5. SCENARIO IV - LIMITED MAINTENANCE

Surveillance that includes some active care or maintenance is site specific and depends upon the ~~size and the~~ configuration of the tailings disposal area. However, for the purpose of developing a cost estimate for the various levels of site surveillance it is assumed that the tailings disposal area covers approximately 100 hectares. This limited maintenance scenario corresponds with the nature of the active care mode of tailings disposal described in Chapter 8, where siting and design features do not eliminate the need for continuing maintenance.

The assumptions upon which Scenario IV is based are:

- Activities under the limited maintenance scenario include inspection, fencing, groundwater monitoring, repair and revegetation of eroded areas.
- Maintenance is limited to the equivalent of one hectare's worth of the tailings disposal area.
- The cost for contracting to repair and revegetate the equivalent of one hectare is approximately \$2,500.[3] This cost includes bringing in topsoil and reseeding as well as limited repair of diversion channels, restabilization of embankments and repair of areas that might erode excessively.

When this cost estimate for repair and revegetation of an area equivalent to one hectare is added to the upper bound estimates for inspection, groundwater monitoring and fencing, the total becomes:

\$8,000 (inspection, groundwater monitoring and fencing) +
\$2,500 (limited maintenance) = \$10,500

It can be postulated that a particular portion of the tailings disposal area would be in need of more or less constant or repeated repair and/or maintenance. In this situation a determination could be made that it would be more beneficial to provide some sort of permanent fix such as covering the area with rip rap. Assumptions for this situation are:

- The equivalent of rip rapping would be necessary in order to repair one hectare's worth of the disposal area.
- The rip rap is laid about a half meter deep and costs $\$20/m^3$.

Based on these assumptions, costs for rip rapping one hectare compute as follows:

$\$20 \times 5{,}000\ (m^3) = \$100{,}000$

This kind of permanent fix would be equivalent in cost to about 12 years of annual maintenance at the level assumed above in this scenario.

6. SCENARIO V - EXTENSIVE MAINTENANCE AND IRRIGATION

Scenario V involves extensive maintenance and revegetation, including irrigation of the tailings disposal area and continued groundwater monitoring.

6.1 Maintenance of Vegetation

As with any scenario involving active care, the cost estimates for the maintenance system depend on the size of the tailings disposal area. Assumptions are:

- The tailings disposal area is assumed to be 100 hectares
- Irrigation equipment, including pump and miscellaneous valves and nozzles for a 100 hectare area, would cost approximately \$107,000.[4] (p. 137)
- Irrigation equipment would need to be replaced approximately every twenty years and equipment costs can be amortized over this period
- Substantial annual operating costs are associated with Scenario V including costs for:

- fertilizer \$30/acre[4] (p. 137)	\$7,500
- power costs for irrigation pump[4] (p. 137)	\$1,858
- maintenance labor and supplies = 10% of irrigation equipment	\$10,700

- operating labor ($25,000 salary, supervision included, x1/4 my)	$6,250
- amortized equipment costs	$5,350
TOTAL	$31,658 or ≅$32,000/site

6.2 Groundwater Monitoring

Assumptions are:

. Submersible pumps placed in five wells and replaced every five years 5 x $1,000 (pump, hose and installation charges) = $5,000 $5,000 ÷ 5 (years) = $1,000	$1,000
. Analysis costs = $750 - $1,000 (see Scenario II)	$1,000
	$34,000/site per year

7. SUMMARY

Table R-1. Alternative Scenario Costs (Upper Bound Cost Estimates)

Scenario I - Passive Monitoring	$ 2,500
. Inspection Costs - $2,000 . Miscellaneous Equipment and NRC Oversight - $500	
Scenario II - Inspection Plus Groundwater Monitoring	$ 7,000
. Inspection Costs - $5,000 . Equipment - $1,000 . Sample Analysis - $1,000	
Scenario III - Passive Monitoring Plus Fencing	$ 8,000
. Inspection, Sampling and Analysis (Scenario II) - $7,000 . Fencing - $1,000	
Scenario IV - Limited Maintenance	$10,500
. Inspection, Groundwater Monitoring and Fencing - $8,000 . Repair and Revegetate 1 ha - $2,500 . Rip Rap (permanent fix) 1 ha - $100,000	
Scenario V - Extensive Maintenance and Irrigation	$34,000
. Maintenance of Vegetation - $32,000 . Groundwater Monitoring - $2,000	

REFERENCES

1. NUREG-0268 "Determination of Proposed License Fees for Fiscal Year 1977," 42 Fed. Reg. 22149 (1977).
2. NUREG/CR-0311, "Groundwater Elements of In Situ Leach Mining of Uranium," Geraghty & Miller, Inc. August 1978, p. 50.
3. Ch. 11 - Table 11.2
4. M. B. Sears *et al.*, "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluent in the Nuclear Fuel Cycle for Use in Establishing as Low as Practical Guides - Milling of Uranium Ores," Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-TM-4903, Vols. 1 and 2, May 1975.

APPENDIX S. SENSITIVITY ANALYSIS OF CUMULATIVE IMPACTS

Estimates of cumulative impacts (1979-2000) from uranium milling (Section 6.4, Section 9.3, and Chapters 12 and 15) are sensitive to several key parameters. Parameters that are important in estimating cumulative impacts include: (1) nuclear power projections; (2) enrichment tails assay policies; (3) projections of future ore grade; (4) depth of tailings piles; and (5) unit area radon flux rates. Since there is uncertainty in all of the above parameters, there is an uncertainty in estimates of cumulative impacts that depend on these parameters. The purpose of this appendix is (1) to discuss the uncertainties in the above parameters and estimate a range for them, and (2) to provide a range on the more significant cumulative impacts such as land permanently committed to tailings disposal and residual radon releases. In addition to uncertainty in source terms, there are uncertainties in transport estimates and health effects that occur as a result of radon releases. No attempt is made to quantify uncertainties associated with transport estimates. Ranges of uncertainty with regard to health effect estimates are discussed in Appendix G.

Nuclear Power Projections

Land commitments and radon releases will generally vary directly with the amount of nuclear power generation. Nuclear power growth projections through the year 2000 are highly speculative. Projections used in this document were taken from projections by the Department of Energy (DOE). DOE's most recent projections for nuclear capacity in the year 2000 extend from a low of 160 GWe to a high of 200 GWe.[1] DOE's mid-range projection is that used in this document (180 GWe). Consequently, the range on nuclear power in the year 2000 is taken to extend from 160 to 200 GWe.

Cumulative U_3O_8 requirements are approximately proportional to nuclear capacity estimates for the year 2000. The range on cumulative U_3O_8 requirements thus extends from 500,000 to 630,000 MT of U_3O_8. Cumulative impacts on land committed to tailings disposal, radon releases, and health effects are approximately proportional to the nuclear capacity estimates for the year 2000. In addition to the uncertainties in nuclear power projections there is also an uncertainty in the estimate of the percentage of U_3O_8 that will be filled by conventional milling. This document has assumed that 77% of U_3O_8 requirements would be filled by conventional milling. The basis for this assumption is given in Chapter 3.

Enrichment Tails Assay

Enrichment tails assay depends on DOE's uranium enrichment policies. The enrichment tails assay assumed in this document is 0.20 percent U-235.

Recently, DOE reduced the enrichment tails assay from 0.25 percent U-235 to 0.20 percent U-235.[2] If a 0.25 percent tails assay were maintained until the year 2000, then cumulative U_3O_8 requirements would be about 12 percent higher than those used in this document. DOE has also indicated that the tails assay might be increased to 0.25 percent in the late 1980's. Consequently, the average enrichment tails assay is expected to remain in the range of 0.20 percent to 0.25 percent.

Average Ore Grade

The average ore grade used for all evaluations in this document is 0.10 percent. During 1979 the average grade of ore processed in 21 operating conventional mills was about 0.12 percent, down about 15 percent from the previous year.[3] Although future ore grades are somewhat speculative, the grade of ore that will be processed in the year 2000 has been predicted to be about 0.08 percent, with ore from underground and open pit mines averaging about 0.10 and 0.06 percent, respectively.[4] The grade of 0.10 percent was thus selected to represent the average grade of ore processed over the period 1979 through the year 2000. The range of this value, as used for the calculation of cumulative industry impacts, is taken to be from 0.08 percent to 0.12 percent. Ore grade assumptions affect both the volume of tailings generated and the activity concentration of tailings. The tailings volume is inversely proportional to the ore grade. Tailings activity concentrations are directly proportional to the ore grade. If the depth of tailings is held constant, then decreasing the ore grade results in increasing the land permanently committed to tailings disposal. However, since the increase in tailings area is balanced by a decrease in activity concentration, there is no net increase in cumulative radon releases from uncovered tailings.

Radiological impacts resulting from individual mills, such as those described in Section 6.2.8, are directly proportional to the assumed ore grade being processed. Monthly average ore grades for individual mills currently range from about 0.03 to 0.30 percent.[3] Therefore, all radiological impacts occurring from a single model mill processing 0.10 percent ore could vary by approximately a factor of 3 in either direction. (This range of variability does not apply to cumulative industry impacts, however, as they vary as a function of industry-average ore grade as described above.)

Effective Depth of Tailings Piles

Cumulative radon releases are estimated simply by multiplying total areas of tailings piles by unit area radon flux rates. The total surface area of tailings estimated to exist in the future is a function of the projected volume of tailings and the effective average depth of piles which exist at the time of projection. Therefore, given projections of nuclear power growth, enrichment policies, and ore grade, an effective depth of tailings must be assumed to estimate area and total future radon releases. For a fixed volume, varying effective tailings depth will result in inversely proportional changes in radon flux estimates; doubling depth halves release, for example.

In Sections 6.4 and 9.3.8, a very conservative value of effective tailings thickness of about 6.5 m is used, based on an assumed dry bulk density of 1.6 MT/m^3. (Note: In the cost evaluation of alternative tailings disposal programs for the model mill in Appendix K, and Chapter 11, a depth of about 8 m was assumed.)

Thicknesses, shapes, and surface areas of tailings piles are highly variable, being dependent upon site-specific topography and tailings management practices. Review of current information on tailings volumes and surface areas indicates the effective depth of existing active piles is between about 12 and 13 m, or about two times the value assumed. The proposed regulatory requirements concerning tailings management may influence the depth of piles (for example, covering requirements could lead to increasing depths to minimize areas and costs), but this is not possible to predict. However, effective thickness could reasonably be expected to go as high as 15 m.

Specific Radon Emission Rate

Once total tailings surface areas are estimated, radon releases are determined by multiplying by unit area radon flux rates. After final covering of tailings disposal areas, flux rates will be determined by regulatory limits (2 pCi/m^2-sec above background is proposed).

During operation estimates of flux are made by assuming homogeneity of tailings and multiplying average tailings radium concentration by a factor which is dependent upon the tailings radon attenuation properties (Appendix P). This factor, herein termed the specific radon rate, will be variable and a conservative value of one pCi/m^2-sec per pCi/g of radium was used in making cumulative radon release estimates. On the basis of information obtained on radium concentrations in soils and measured soil flux rates (as discussed in Appendix O), the value is probably between 0.5 to 1.0 pCi/m^2-sec per pCi/g radium for tailings near the moisture content of natural soils. Decreasing the factor by half would obviously reduce releases by one half.

Range of Cumulative Impacts

Table S.1 contains a summary of the range of values for five key parameters affecting cumulative impacts. Since it is unlikely that all of the parameters would stack up on either the low or the high side, the staff has estimated a range for the different cumulative impacts. The staff's estimate of the range of the different cumulative impacts is given in Table S.2. These estimates are based on the foregoing analysis of the ranges in individual parameters, and are derived by multiplying the value used herein by the square roots of the ratios of the extreme values to the value used.

Table S.1 Summary of Ranges and Values Used for Key Parameters Affecting Cumulative Impacts

Parameter	Range	Value Used In Document
Nuclear Power Projections for Year 2000 (GWe)	160-200	180
Enrichment Tails Assay (% U-235)	0.20-0.25	0.20
Ore Grade (%)	0.08-0.12	0.10
Depth of Tailings (m)	6.5-15	6.5
Specific Radon Emission Rate (pCi/m^2-sec/pCi/gm)	0.5-1.0	1

Table S.2 Summary of Ranges for Cumulative Impacts

Impact	Estimated Range	Value Used In Document
Land Permanently Committed to Tailings Disposal and Limited Use (ha)	3400-7600	6100
Persistent Radon Releases from Uncovered Tailings (KCi/yr)	220-670	540
Persistent Continental Health Effects from Uncovered Tailings (premature deaths/yr)	1.6-10.8	6.0
Persistent Radon Releases from Covered Tailings (KCi/yr)	1.6-4.9	3.9
Persistent Continental Health Effects from Covered Tailings (premature deaths/yr)	0.01-0.08	0.04

References

1. "Annual Report to Congress-1979," U.S. Dept. of Energy, Energy Information Administration, July 1980.
2. W. R. Voigt, "Uranium Enrichment Policies," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978.
3. J. F. Facer, Jr., "Uranium Production," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1979.
4. J. Klemenic, "Uranium Production Capability in the United States", presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1979.

APPENDIX T. PROFILES OF OPERATING CONVENTIONAL U.S. URANIUM MILLS

T.1 INTRODUCTION AND SUMMARY

This appendix presents brief profiles of the 22 currently operating U.S. uranium mills. Much of the information presented is taken from the U.S. Environmental Protection Agency's report entitled, "Environmental Study on Uranium Mills," Part I, Volume 1 and 2, Appendix C, February 1979. Information from the EPA report (baseline year 1977) has been supplemented or amended as necessary to reflect the more recent information pertaining to the sites examined. It must be emphasized that some of the facets and details of the programs described would not meet the standards being implemented for new mills and some upgrading, as described in Section 12.4, will be mandatory. NRC licenses, by license condition, are subject to revision as necessary to achieve conformance with the new standards.

Important basic information is summarized in Table T.1, "Profile of U.S. Uranium Mills in Operation." As can be seen from the table, ore feed capacity for all 22 operating mills totals 50,700 MT per day for an average capacity of 2300 MT per day per mill. Most mills are smaller than the average, with median capacity for the industry being approximately 1600 MT per day. The largest operating mill, Kerr-McGee's Grant operation, has a capacity of 6300 MT per day, while the smallest operation in the U.S., Dawn Mining Co. in Washington state, has a capacity of 400 MT per day. Six of the 22 mills produce molybdenum or vanadium byproducts. Eighteen of the 22 mills have acid leach circuits only. Of these, eleven concentrate uranium values by solvent extraction, three by ion exchange, and four by the eluex process (SX used as a second stage of purification following IX). Two-stage acid leaching is employed at four mills. Two mills have alkaline leach circuits only, and use no method of concentration. Two-stage leaching is employed at both of the alkaline leach mills. The Atlas and Cotter mills have both acid and alkaline circuits. In alkaline leach circuits, yellowcake is precipitated with sodium hydroxide and ammonia in a two-stage process. For the acid leach mills, ammonia is the most common precipitation reagent, being used alone or in combination with other reagents in all but the Anaconda mill, which uses MgO as the sole precipitation reagent.

The amount of pond liquid recycled for use in the mill and the degree of recycle within the process are the key parameters which should be used in evaluating conservational water reuse in the mill. In Table T.1, the former parameter is examined. Information on in-process recycle can be found in the EPA report. Recycle from the impoundment can be used to provide solution for either process operations or tailings dilution. The latter has little effect on fresh-water use since it serves only to facilitate pumping of the tailings slurry. For this reason, Table T.1 considers only recycling for process operations. Of the 19 operating mills with known balances, eight practice no recycle. For three mills, 0-25% of the total water used in the mill process is recycled from the tailings pond: for three mills, 25-50%; for four mills, 50-75%. For one mill, 83% of the total water used in the mill process is recycled from the tailings pond.

Treatment of mill wastes always involves impoundment, with disposal by evaporation. In two cases, mill waste solutions are neutralized by lime addition and/or treated by barium chloride coprecipitation (2 cases), or ion exchange (1 mill). The Uravan mill is the only U.S. uranium mill that operates a point discharge. It also practices occasional lime neutralization of solvent extraction raffinate prior to discharge. Only one operating mill (Union Carbide, Gas Hills) is using subsurface impoundment for tailings disposal (a mined-out open pit).

In this appendix, "total tailings area" refers to the dam and embankment area, the pond area containing the tailings and solution, as well as the area occupied by any associated evaporation or decant ponds. "Tailings pond area" refers only to the area containing the tailings and solution.

Table T.1. Profile of U.S. Uranium Mills in Operation

Location	Company	Maximum Capacity (MT per day)	Mining* Method	By-Products	Leaching Process	Tailings Pond Area (acres)	Ra-226 (pCi/g)	Amount of Tailings ($x10^6$ MT)	Recycle for Process Use Constitutes x % of Total Water Used in Mill Circuit
COLORADO									
Canon City	Cotter	1300	UG	V-solution	Acid (2-stage)	200	780	1.0	-
Uravan	Union Carbide	1200	UG	V_2O_5 solution	Acid (2-stage)	79	476	8.8	-
NEW MEXICO									
Cebolleta	Sohio/Reserve Oil & Minerals	1500	UG	None	Acid	60	504	1.4	0
Church Rock	United Nuclear	3600	UG	None	Acid	197	290	2.2	0
Grants	Anaconda	6200	OP+UG	None	Acid	270	620	32	0
Grants	Kerr-McGee	6300	UG	Mo concentrate	Acid	250	615	24.6	0
Grants	United Nuclear/ Homestake Partners	3100	UG	V-solution	Alkaline (2-stage)	150	385	16.8	17
TEXAS									
Falls City	Continental Oil/ Pioneer Nuclear	2900	OP	None	Acid	220 (Total tailings area)	-	5.6	83
Panna Maria	Chevron Resources	2200	-	None	Acid	250 (Total tailings area)	-	1.2	-
UTAH									
Blanding	Energy Fuels Nuclear	1800	-	V-solution	Acid	333	422	0	0
La Sal	Rio Algom	640	UG	None	Alkaline (2-stage)	35	560	1.6	74
Moab	Atlas	1100	UG	V-solution Cu Conc.	Acid + alkaline	115	540	7.8	57

Table T.1. Continued

Location	Company	Maximum Capacity (MT per day)	Mining* Method	By-Products	Leaching Process	Tailings Pond Area (acres)	226 Ra (pCi/g)	Amount of Tailings (x10^6 MT)	Recycle for Process Use Constitutes x % of Total Water Used in Mill Circuit
WASHINGTON									
Ford	Dawn Mining	400	OP	None	Acid (2-stage)	106	-	2.8	0
Wellpinit	Western Nuclear	1800	OP	None	Acid	42	-	1.3	43
WYOMING									
Gas Hills	Federal-American	900	OP+UG	None	Acid	105	420	4.2	0
Gas Hills	Pathfinder	2500	OP	None	Acid (2-stage)	70-80	420	5.8	59
Jeffrey City	Western Nuclear	1500	OP+UG	None	Acid	85 (Total tailings area)	429	11.0	0
Natrona	Union Carbide	1200	OP	None	Acid	148 (Above-ground) 26 (pit)	309	7.6	56
Powder River	Exxon	2700	OP+UG	None	Acid	200	450	5.7	0
Powder River	Rocky Mt. Energy	1800	OP	None	Acid	150 (Total tailings area)	420	8.0	29
Shirley Basin	Pathfinder	1600	OP	None	Acid	150	540		21
Shirley Basin	Petrotomics	1500	OP	None	Acid	160	570	2.8	16

* OP = Open pit; UG = Underground.

T.2 PROFILES OF OPERATING URANIUM MILLS

T.2.1 Canon City Mill, Cotter Corp.

The new Canon City Mill at Canon City, Colorado, is operated by Cotter Corp. (a subsidiary of Commonwealth Edison) to recover uranium and vanadium through use of a two-stage acid leach process. Ore is supplied from underground mines owned by the company in southwestern Colorado and from the Schwartzwalder Mine near Golden, Colorado, 190 km (120 miles) away.

The new acid leach mill, which was completed in 1979, replaced Cotter Corp.'s alkaline leach mill, which had been in operation since August 1958. The original mill was a large pilot plant which could process about 68 MT per day. Over the 20-year period, the original mill was expanded to a capacity of 1088 MT per day. The original tailings dam was developed from a starter dike; further construction of the tailings impoundment was done with mechanical equipment using tailings sands. To improve tailings management, the company constructed their first lined pond in 1971. It covered an area of about 0.8 ha (2 acres). In 1973, a second lined pond was constructed, covering 5.3 ha (13 acres). The dam was about 7.6 m (25 ft) high and impounded about 2.5 × 10^5 m^3 (200 acre-ft). The pond was used for evaporation of mill liquids and contained a limited amount of solids.

Over the years, tailings liquid has seeped from the old tailings impoundment. Cotter Corp. placed the new mill at the old site, so that a single impoundment could satisfy the requirements for the new mill, plus provide a place for relocation of the old mill tailings.

The new tailings impoundment was put in use on August 3, 1979. The impoundment is divided into two compartments to accommodate tailings from three different process systems: the new acid leach mill, the old alkaline leach mill, and a nearby spent catalyst plant that generates alkaline waste from the extraction of five different metals from spent catalyst. The primary portion of the impoundment receives tailings from the new mill. Tailings from past alkaline-leach milling operations are being reprocessed in the old mill and placed in the secondary portion of the impoundment.

The main tailings dam is being constructed in stages by the downstream method. A section through the dam from upstream to downstream includes the liner cover, the Hypalon liner, the core, the sand chimney drain, and the shell. The impoundment contains subdrains for collection of any water that might come from underground sources. The secondary dam used to form the secondary portion of the impoundment has been constructed to its ultimate height during the first construction period. The primary dam will be raised to its ultimate height in two or three additional stages. The storage volume in the primary and secondary impoundments are 7.6 × 10^6 m^3 (6200 acre-ft) and 1.7 × 10^6 m^3 (1350 acre-ft), respectively.

T.2.2 Uravan Mill, Union Carbide Corp.

The Uravan Mill is in Western Colorado in an area of rugged canyons and mesas. It is 80 km (50 miles) south of Grand Junction, Colorado. The mill is adjacent to the San Miguel River, a tributary of the Colorado River. Uranium, vanadium, and radium recovery operations were begun at the site in 1915 by the Standard Chemical Company. The Union Carbide Corp. purchased the property in 1936, and since that time, except for a period between 1946 and 1950, has produced either vanadium, uranium, or both at the site.

The Uravan Mill at various times has processed ore from more than 200 mines; individual mines delivered from as little as 90 MT (100 ST) to more than 900,000 MT (1 × 10^6 ST) of ore. Presently, the mill receives ore from about 20 underground mines; five of which are company owned and supply about 85% of the Uravan mill feed.

Vanadium is almost invariably present with uranium in the ores of the Uravan mineral belt in ratios that vary from 3:1 to 10:1, vanadium to uranium. For this reason, vanadium product liquor (18% V_2O_5) is the major mill product, with lesser quantities of yellowcake (85% U_3O_8). The ore must be subjected to a hot, highly oxidizing two-stage acid leach to achieve economical recovery of uranium and vanadium.

The variety of mill effluent streams are segregated for separate treatment. The mill employs a pond system consisting of tailings ponds, solvent extraction raffinate ponds, and barium chloride ponds, all of which are unlined. The tailings pond receives waste slurry from the CCD circuit [14 L/s (220 gpm)]. After settling, a portion of the liquid is decanted and returned to the mill as a wash solution for CCD [11 L/s (175 gpm)]. The tailings ponds cover a combined area of about 32 ha (79 acres) on a hillside adjacent to the mill. Seepage collected in the toe dam is recycled to the mill process. Hillside runoff is treated with barium choride and is discharged to the San Miguel River at a rate of 9 L/s (150 gpm).

A solvent extraction raffinate area, located across the river from the mill, receives barren solution from the vanadium SX section of the mill. The effluent contains about 100 to 200 mg/L vanadium and high TDS in the form of AL and SO_4. This raffinate covers an area of 12 ha (30 acres).

The Uravan Mill is the only uranium mill in the United States directly discharging liquid effluent. A composite waste stream consisting of tailings pond seepage, yellowcake thickener overflow, cooling water, and occasionally the neutral solution from lime treatment of the vanadium SX raffinate is released to the San Miguel River. These effluents first are treated with barium chloride, settled in a series of ponds, monitored, and discharged under a National Pollutant Discharge Elimination System (NPDES) permit.

T.2.3 L-Bar Mill, Sohio Petroleum Co./Reserve Oil & Minerals

The L-Bar Uranium Mill is located in an area of flat terrain about 29 km (18 miles) north of Laguna, New Mexico. Ore for the mill is obtained from an underground mine that works the Jackpile Sandstone formation. The mine and mill are operated by Sohio on 1200 ha (3000 acres) of the 49,000-ha (120,000-acre) L-Bar Ranch.

The mill, which uses an acid-leach process, began operations in 1976 with a capacity of 1500 MT per day. Sufficient ore is proven to maintain this rate for 10 to 15 more years. A typical ore sample contains 0.225% U_3O_8, 0.08% V_2O_5, 1.01% iron, and 0.12% sulfur. Water for milling operations is obtained from wells and mines. In addition to the extensive use of in-process recycle, the company intermittently recycles water from the tailings pond to repulp tailings. A problem peculiar to the L-Bar mill has been zirconium buildup in the SX organic solvent. To remedy this, the organic phase is stripped of Zr and Mo in the final SX mixer-settler unit, and a bleed stream containing Mo and Zr is disposed of in the impoundment system.

The L-Bar mill uses a pond system consisting of a tailings pond with catchment basin and two solvent extraction raffinate ponds. The tailings impoundment is an above-ground impoundment built on natural materials with an engineered earthen starter dam to the west that keys into the natural topography on the north and south. In addition, there is a small saddle dam to the east. The dam has been lifted by the upstream method of spigotting of tailings. Of the total impoundment area of 73 ha (180 acres), about 50 5o 60 acres are covered with tailings. The surface area of liquid in the impoundment is about 30 ha (75 acres). The pile consists of approximately 1.4 × 10^6 MT of tailing material and reaches a maximum height of 7 m (23 ft). The tailings pond is lined with treated clay. Raffinate ponds are unlined. Waste flow to the tailings pond is composed of tailings slurry containing 1500 MT (1660 ST) per day of solids and 18 L/s (280 gpm) of waste solution. About 11 L/s (170 gpm) of SX raffinate is sent to the raffinate ponds, the exact amount depending on the amount of tailings pond decant recycled.

T.2.4 Church Rock Mill, United Nuclear Corp.

Site topography at United Nuclear's Church Rock Mill [32 km (20 miles) northeast of Gallup, New Mexico] is characterized by rolling hills. The mill, which opened in 1977, was designed to use acid leach extraction to process 3600 MT (4000 ST) of ore per day from company-owned underground mines. The ore contains 0.15 to 0.20% U_3O_8. Fresh water for mill operations is obtained from underground mines. Yellowcake is the only mill product.

The tailings pond is formed by a dam built from native clays and compacted coarse tailings. The pond has three compartments separated by earthen embankments. The total surface area of tailings including dam and storm water interceptor ditch is 83 ha (204 acres). The area in use as of April 23, 1980, is 80 ha (197 acres). The surface area of liquid on tailings ia about 11 ha (28 acres). The maximum depth of tailings is approximately 15 m (50 ft). The storage capacity of the pond is now about 10 × 10^6 m^3 (365 × 10^6 ft^3). The available evaporative area will be 65 ha (160 acres).

In July 1979, a break in the tailings dam spilled about 350 × 10^6 L (93 × 10^6 gallons) of effluent and 1000 MT (1100 ST) of tailings on or into nearby soil and streams. The streams carried the spilled tailings to Rio Puerco, through Navajo grazing lands, and finally into Arizona. The mill was temporarily closed and corrective measures were taken. The mill reopened in the fall of 1979. Cleanup efforts are still in progress.

T.2.5 Bluewater Mill, Anaconda Co.

Anaconda's Bluewater Uranium Mill is located in the heart of the Grants Mineral Belt, about 15 km (10 mi) northwest of Grants, New Mexico, in a small alluvium and volcanic-filled valley known as the San Jose River Valley. The Zuni Mountains, a northwest-trending range, lie about 25 km (15 mi) southwest of the mill. Mesas surround the San Jose River Valley to the north, east, and south.

From 1953 to 1956, the mill extracted uranium using a carbonate leaching process. Parallel mill circuits were provided in 1955 to permit both alkaline and acid leaching of limestone and sandstone ores. By 1959, it was more economical to treat the available ore in the acid-process mill and consequently, the carbonate mill was shut down. Between 1955 and 1978, the Bluewater Mill extracted uranium from a throughput of 3500 MTPD of ore containing about 0.25% U_3O_8. Since completion of a recent expansion, the mill has processed an average of 5400 MT per day of ore with an ore quality of less than 0.2%. The acid leach process now used differs from the usual acid leach circuit in that MnO_2 is used as an oxidant (rather than $NaClO_3$) and MgO is the precipitation reagent (rather than NH_3).

The tailings from the mill are pumped to an abovegrade impoundment about 8 m (25 ft) above the basaltic rock formation. The tailings retention area is constructed in a natural basin to the north of the mill area. The tailings pond consists of an earthen embankment on all sides. The downstream faces of the embankments have a 2:1 slope and in some areas are covered with vegetation. The upstream slope is riprapped in areas where necessary. The total surface area of the tailings pile is 108 ha (266 acres), and the area of liquid on the pile is approximately 12 ha (30 acres). The maximum height of the tailings pile at the south end is approximately 18 m (60 ft). There are approximately 17×10^6 mT of tailings in active pile. Inactive tailings from the former carbonate-leaching process are located southeast of the active tailings pond. In late 1977, these inactive carbonate leach tailings were covered with an average of 85 cm (35 inches) of siltclay. The dry area of the carbonate impoundment is presently about 6 ha (14 acres). Inactive tailings of the old acid-leaching process are located along the northwestern edge of the active tailings pond and have a dry area of about 14 ha (35 acres). Tailings in all of the impoundments total 32×10^6 MT (35×10^6 ST).

Before reconstruction of the present dikes, tailings overflows were collected in catch basins. Overflow deposits in the catch basins are about 125 cm (49 inches) deep. The tailings management plan was altered in 1978 when additional evaporation ponds were built and a new tailings discharge process was implemented to increase moisture in the beach area. Four decant ponds totaling 221 acres are in operation and phased plans call for construction of 11 more such ponds as needed.

T.2.6 Ambrosia Lake Mill, Kerr-McGee Nuclear Corp.

Kerr-McGee's Ambrosia Lake Mill is the largest uranium mill in the United States. It is located in the Grants Mineral Belt about 40 km (25 miles) north of Grants, New Mexico. The mill extracts uranium and molybdenum by-products with two parallel acid-leach processing circuits that are operated simultaneously.

The mill began operations in November 1958 with a rated capacity of 3270 MT per day. Capacity has since been expanded to 6350 MT per day, and sufficient ore is proven to maintain this processing rate for at least 20 more years. Seven company-owned underground mining operations at Church Rock and Ambrosia Lake and several toll shippers supply the required ore.

All process water used in the mill is obtained from the underground mines and is treated by ion exchange before being fed to the mill. About 1% of the total U_3O_8 produced in the mill is attributed to mine water treatment. Treated mine water not used in the mill is used by a local rancher for agricultural purposes.

Kerr-McGee has about 23×10^6 MT (25×10^6 ST) of tailings at its Ambrosia mill. The tailings impoundment system consists of 21 tailings and decant ponds covering 140 ha (350 acres). The total active tailings pile surface area is 100 ha (250 acres). About 16 ha (40 acres) of the pile's surface area is covered by tailings solution. The pile reaches a maximum height of about 30.5 m (100 ft). The tailings dam is constructed of coarse tailings and slimes.

Decant solution and lateral seepage from the tailings ponds is collected in a catchment basin from which each of the decant ponds can be filled. The pond system may also be operated in a cascade fashion, with overflow from one decant pond being sent to another. The newest decant ponds are lined with 0.25-mm polyvinyl chloride on the bottoms and 0.51-mm chlorinated polyethylene on the sides.

A June 20, 1977, amendment to the operating permit for the Ambrosia mill allows 7300 MT (8000 ST) of tailings per month from milling operations to be used in backfilling a nearby underground mine.

T.2.7 Grants Mill, United Nuclear-Homestake

United Nuclear-Homestake operates the Grants Uranium Mill 16 km (10 miles) northwest of Grants, New Mexico, in the Ambrosia Lake mining district. The mill opened in 1958 at a design throughput capacity of 1587 MT per day; this was increased to 3100 MTPD in 1967. Current production averages 2300 MT per day, split evenly between production from underground mines, which are less than 32 km (20 miles) from the mill, and "toll" ore. Toll ore, about 15% of which is in limestone, has an average grade of 0.10% U_3O_8; the ore from underground sandstone mines averages 0.15% U_3O_8. In addition to yellowcake production, an 8% vanadium by-product (in solution) is recovered.

On February 8, 1977, a break in the mill tailings dam resulted in the entire tailings pond spilling into vacant land controlled by the mill operator. The spill covered an area of 10 to 20 ha (25 to 50 acres) and was several centimeters deep.

The Grants Mill differs from other New Mexico Mills in two basic ways: (1) ore is leached with alkaline solution, and (2) precipitation of yellowcake does not depend on first passing pregnant solution through ion-exchange or solvent-extraction circuits. The mill practices both process recycle and recycle for tailings dilution. Because an alkaline leach process is employed, ore is finely ground to expose more uranium to the leach solution. As a consequence, fine tailings are produced. The tailings are discharged to an abovegrade impoundment covering a total area of 105 ha (260 acres). The total active tailings pile surface area is 60 ha (150 acres) at the base. Approximately 20 ha (50 acres) of the pile's surface area is covered by tailings solution to a maximum depth of 0.46 m (1.5 ft). As of April, 1980, the active pile consisted of approximately 16.8 MT of tailings material and reached a maximum height of 26 m (85 ft). United Nuclear-Homestake maintains 1.5 m (5 ft) of freeboard and 15 m (50 ft) of beach.

The subsoil is about 27 m (90 ft) thick with reasonably high permeability, which aggravates problems due to seepage from the tailings pond. The subsoil is underlain by a sandstone formation and an aquifer is located under the ponds. Seepage from the pond is being controlled by the use of downgradient collection wells to pump groundwater contaminated by pond seepage up from 12 to 18 m (40 to 60 ft) depths for return to the pond.

T.2.8 Conquista Mill, Continental Oil/Pioneer Nuclear

The Conquista Mill is located near Falls City, Texas, about 48 km (30 miles) southeast of San Antonio. It is the only open-pit uranium mine-mill complex in the state. The project is a joint venture of Continental Oil (operator) and Pioneer Nuclear.

The mill has been in operation since 1972 and is expected to continue through 1990, when ore reserves will be depleted. The production includes about 540 MT per day of toll-processed ore from Exxon Minerals' Felder open-pit mine in Live Oak County.

The mill recycles nearly 100% of the water sent to the main tailings pond--less the amount evaporated and the amount entrained with the solid tailings. Tailings slurry and SX raffinate bleed are pumped to the tailings pond. A separate impoundment is provided for the composite stream of barren solution from uranium precipitation and waste extract from the molybdemum scrubber in the solvent extraction circuit. These are solutions that cannot be recycled because they are contaminated with high levels of dissolved salts or metallic impurities. Provisions have been made to collect any pond seepage; however, since plant startup, no seepage has been detected. This is attributed to the underlying bentonitic clay and natural shale.

One side of the tailings pond has been keyed into the side of a hill. Dikes have been built around the other three sides of the impoundment. The embankment consists of clays and earthen materials. The mill operators expect to raise the dikes another 6 m (20 ft) in the near future. Currently, the tailings pond is half covered with water.

T.2.9 Panna Maria Mill, Chevron Resources Co.

The Panna Maria Mill, located 160 km (160 miles) northwest of Corpus Christi, Texas, began operations in January 1979. The mill processes about 2700 MT per day of a mixture of low-, medium-, and high-grade sandy clay ore, averaging 0.07% U_3O_8.

Tailings are contained in an aboveground impoundment surrounded by dikes. The dikes have clay interiors keyed onto a natural clay base. A dike partition separates the tailings pond into two compartments, only one of which is currently in use for tailings storage.

T.2.10 White Mesa Mill, Energy Fuels Nuclear, Inc.

The White Mesa Uranium Mill is near the western edge of the Blanding Basin in southeastern Utah, about 8 km (5 miles) south of Blanding, Utah. The site is located on a nearly flat peninsula platform (White Mesa) tilted slightly to the south-southeast and surrounded on almost all sides by deep canyons, washes, or valleys. The mill and associated tailings disposal ponds are on Blanding silt loam, a deep soil formed from windblown deposits of fine sands and silts.

The mill, operated by Energy Fuels Nuclear, Inc., began operations in July 1980. It is expected to have an operating lifetime of 23 years. The site consists of 600 ha (1480 acres), 190 ha (480 acres) of which will be used for milling, tailings disposal, and related activities. There will be no onsite mining activities. Mines within 160 km (100 miles) of the company's ore-buying stations (in Blanding and Hanksville) will supply the required ore. Energy Fuels Nuclear controls reserves of about 8600 MT (9500 ST) of U_3O_8. Principal uranium minerals in the sedimentary host rock are uraninite and coffinite. Only uranium, vanadium, and copper are present in sufficient quantities to warrant processing. At present, copper extraction is uneconomic.

The mill will utilize an acid-leach, solvent-extraction process to recover about 730 MT (800 ST) of U_3O_8 annually. Vanadium by-product recovery is expected to yield 1500 MT (1600 ST) annually, containing less than 0.005% U_3O_8 in the final vanadium product. The mill will use about 5.9×10^5 m^3 (480 acre-ft) of water per year from the Navajo sandstone aquifer. No recycle of ponded water is planned.

Tailings will be produced at a rate of about 1800 MT (2000 ST) of solids per day and will be discharged in a water slurry (pH 1.4-1.8; 50% solids) to a six-cell impoundment system (two cells for evaporation and four for tailings disposal) that will cover 130 ha (330 acres). The tailings system features simultaneous construction, operation, closure, and reclamation activities. Each cell will have a maximum area of 40 ha (100 acres). There could be two cells drying or undergoing reclamation while a third is being filled. This system is designed to store 15 years' production tailings, and the total volume of tailings expected to be produced over the project lifetime will approach 7×10^6 m^3 (2×10^8 ft^3). The evaporation cells and one tailings cell will be lined with a multicomponent liner of synthetic material and clayey-silt; the remaining cells will be lined with a 0.6-m (2-ft) layer of compacted clay.

T.2.11 Lisbon Mill, Rio Algom Corp.

The Lisbon mine-mill complex is located in a valley in a mountainous region in Utah, about 48 km (30 miles) southeast of Moab. The mill has been in operation since 1971 and, based on projected tonnage of reserves plus a contingency for unknown additional ore, is expected to continue operations for about four to five years, beginning about December 31, 1979. Ore is obtained from underground mines located adjacent to the mill.

The Lisbon alkaline-leach mill has the lowest specific fresh-water use of any mill in the country. In addition to in-process recycle, recycle from the tailings pond to the filtration stage is practiced. Uranium is recovered from pond water by ion exchange (37% efficient). Cross-country aeration (oxidation by flowing in one open trench) and barium chloride coprecipitation of mine water recovered from a depth of 823 m (2700 ft) are used to oxidize hydrosulfides and reduce radium concentrations to acceptable levels prior to discharge of the water to a local agricultural user.

The tailings retention area was constructed by erecting an earth-fill, clay-core dam across a natural basin. The impoundment consists of two tailings ponds situated in a small west-trending drainage area of slightly more than a square mile. The ponds are designated as "upper" and "lower" tailings ponds. The upper pond lies directly upstream and east of the lower pond such that the rear of the lower pond is adjacent to the mill site. Although both ponds are unlined, they are dug into natural clay to reduce wastewater seepage rates. In the spring, mine water is pumped to the lower tailings pond to extract uranium and sodium. Pond water is then decanted to the upper pond, where it can be recycled to the mill.

At mill startup, tailings were deposited in the lower tailings pond only. The upper pond was built in 1974 but not used until 1976. The lower pond has reached its full storage capacity, and all tailings are being discharged into the upper pond. As of the end of 1979, about 1.6×10^6 MT (1.8×10^6 ST) of ore had been processed at the mill, resulting in about 1.1×10^6 m^3 (940 acre-ft) of tailings contained in the two tailings ponds.

Since there is only a small amount of capacity remaining in the storage area of the upper tailings pond, Rio Algom has recently proposed raising the existing lower tailings embankment by 7.6 m (25 ft). Such a raise would provide sufficient tailings storage for the next five years of mill operation.

T.2.12 Moab Mill, Atlas Minerals Division of the Atlas Corp.

The Moab Mill is located in a mountainous area in Utah on the Colorado River about 5 km (3 miles) northwest of the city of Moab. The mill processes ores from the Big Indian area and from several small private mines from other districts.

The mill has undergone several major process changes since operations began in November 1956. Primarily because of changes in the ore, the original acid process was changed to an alkaline process utilizing the same resin-in-pulp equipment. In 1968, an acid-leaching and solvent-extraction process was added, with recovery of vanadium from the acid-leach circuit and copper from the alkaline leach circuit. For many years, the mill wastes were discharged into the Colorado River, but this practice was stopped in 1977 and all liquid wastes now are impounded in a tailings pond. In addition, the alkaline-leach processing circuit has recently been altered to reduce liquid effluents to the tailings pond.

The acid-leach circuit was designed to process 540 MT (600 ST) daily of vanadium-bearing ores with an average assay of 0.25% U_3O_8 and 1.5% V_2O_5. Recoveries of V_2O_5 and U_3O_8 are about 80% and 96%, respectively. The modified alkaline-leach circuit was designed to process 540 MT

(600 ST) of high-lime and copper-bearing ores daily, with an average assay of 0.20% to 0.25% U_3O_8 and up to 1.0% copper. The circuit will recover U_3O_8 and copper at about 94% and 80% efficiency, respectively. The mill has the capacity to process up to about 1080 MT (1200 ST) of ore per day and to produce up to 830 MT (920 ST) of U_3O_8, 2400 MT (2600 ST) of V_2O_5, and 50 MT (55 ST) of copper annually, depending on ore grades processed.

The mill facilities include a system to treat river water (to reduce hardness), raw wastewaters (to remove suspended and settleable solids), and decant water from the tailings pond (to remove radium by $BaCl_2$ coprecipitation). The solids extracted by the water treatment system are stored in a number of small ponds within the plant boundary. Liquid and solid effluents from the milling operation are impounded in the tailings pond. The tailings impoundment is enclosed by four embankment walls composed primarily of tailings. About 49 ha (120 acres) of the site are covered with tailings to a depth of nearly 25 m (75 ft). The impoundment contains 6.4×10^6 MT (7×10^6 ST) of tailings, and about 3.6×10^6 MT (4×10^6 ST) of additional tailings are expected to be produced through the remaining mill lifetime. To accommodate the additional tailings, supplemental tailings storage volume will need to be provided.

T.2.13 Ford Mill, Dawn Mining Co.

The Ford Uranium Mill (450 MT per day) is operated by Dawn Mining Co. in the rolling hills of eastern Washington State, about 40 km (25 miles) northwest of Spokane. Ore is obtained from the Midnite open-pit mine, about 35 km (22 miles) northwest of the mill. The ore reserves of the Midnight mine, expected to last about four or five years more, are on the Spokane Indian Reservation.

Owned 51% by Newmont Mining Corp. and 49% by Midnite Mines, Inc., Dawn operated from 1957 through 1964 under the AEC's concentrate purchase program. The mill was temporarily shut down in 1965 and then reopened in late 1969 after rehabilitation and reconditioning. To date, more than 4.5×10^6 kg (10×10^6 pounds) of U_3O_8 has been recovered from about 2×10^6 MT (2.2×10^6 ST) of ore averaging 0.225% U_3O_8.

The Ford Mill incorporates a two-stage agitation acid-leach of uranium from ore and a column ion-exchange circuit consisting of four pressurized cylinders, each containing a fixed bed of anion exchange resins. Precipitation is carried out in two stages. In stage one, the pH is raised with lime to precipitate iron, present in the ore as pyrite. Following separation of the iron precipitate, uranium is precipitated from solution with ammonia in the second stage. Waste rock and solutions are neutralized with lime and pumped to a single tailings pond. ? not true

There is no recycle of water from the impoundment. The company indicates that a considerable amount of silica is solubilized in the leaching process which, if allowed to build up in mill solutions, could decrease ion-exchange efficiency by displacing uranium loading sites on the resin. Therefore, recycle is not feasible at this operation.

The tailings pond is a conventional impoundment, roughly rectangular in shape. The pond is separated into three compartments by natural-material embankments. The pond is unlined, and it is estimated that most of the liquid coming into the tailings pond is lost through seepage. The pond contains approximately 2.8×10^6 MT of tailings with 70% solids. The tailings pond will be filled during 1980 and a new disposal area is being developed for subgrade disposal of future tailings. A pit will be excavated immediately to the south of the present tailings dam. The surface area of the pit will be 11 ha (28 acres). The structure will be 20 m (65 ft) deep and will have a total volume of about 1.5×10^6 m^3 (2×10^6 yd^3), which is adequate for about 13 years of mill production at the rate of 1.5×10^6 MT (1.7×10^6 ST) per year. The entire pit floor and side slope surface will be lined with a reinforced 30-mil synthetic Hypalon liner. Elimination of seepage from the tailings pond area by use of the new lined disposal facility will result in a solution disposal problem and Dawn is considering several process water management plans. It will be about three years before the solution buildup in the pond will become critical.

T.2.14 Sherwood Mill, Western Nuclear, Inc.

The Sherwood Uranium Mill is operated by Western Nuclear, Inc., in western Washington State about 64 km (40 miles) northwest of Spokane, Washington, as part of the Sherwood Uranium Project. Western Nuclear obtains low-grade ore for the mill from an open-pit mine nearby at Wellpinit. The mill and mine are on land leased on the Spokane Indian Reservation. The Sherwood deposits are about 6 km (4 miles) south of the deposits mined for Dawn Mining Co.'s Midnight operation, but the ores for the two operations are different in deposition. Western Nuclear began the Sherwood Project in 1978 on established reserves of 7×10^6 MT (8×10^6 ST) of 0.089% U_3O_8. The ore is emplaced in 23×10^6 m^3 (30×10^6 yd^3) of overburden and waste. The mine operates at a cutoff of 0.02% U_3O_8, and the mill, which uses an acid-leach process, operates at a cutoff of 0.035% U_3O_8.

Tailings slurry from the mill is neutralized by reaction with lime before it is pumped to the tailings pond, which has an area of 17 ha (42 acres). The pond is in a valley immediately south and east of the mill area. The upslope face of the tailings dam, as well as the settling area behind the dam, is lined with Hypalon. The 40-mil liner on the dam face is further protected with a layer of coarse-settled solids. The tailings basin behind the dam is protected by diversion canals.

Solution is decanted from the tailings pond and either recycled to the process or treated with barium chloride to remove Ra-226. The precipitate is deposited in a small Hypalon-lined pond of 372 m^2 (4000 ft^2) south of the tailings pond. Decant from this small pond is evaporated in an unlined pond. Bench-scale tests on samples of neutralized effluent indicate that more than 90% of the Ra-226 is removed by treatment with $BaCl_2$. Maximum capacity of the $BaCl_2$ treatment system is about 760 m^3/day (140 gpm), which represents about 30% of the total liquid effluent to the ponds. An additional 50% to 70% of the effluent can be recycled to the mill to decrease water usage.

T.2.15 Gas Hills Mill, Federal American Partners

The Federal American Partner's (FAP) Gas Hills Mill is in a hilly area of Wyoming, about 80 km (50 miles) east of Riverton. The mill began operating in October 1959 with an initial rated capacity of 470 MT per day and is now licensed for 860 MT per day. Current plans call for the expansion of the mill to about 2000 MT per day. The Eluex process is used at the mill, with ion exchange carried out in a resin-in-pulp circuit. The mill processes ores from surface and underground mines operated by FAP in the Gas Hills area. All of these ore reserves are leased by the TVA. Current ore reserves are sufficient for about ten years of mill operation at the expanded rate of 2000 MT per day. The project life may be extended if additional ore reserves are located.

Mill tailings are being pumped to a conventional aboveground impoundment formed by a peripheral earth dam. Free liquid from the pond is pumped to a decant pond. The tailings pond is projected to reach its maximum capacity by late 1981. FAP is currently evaluating the feasibility of disposing of mill waste below grade in the Sagebrush-Tablestakes open-pit mine. The total belowgrade tailings area would be about 24 ha (60 acres) and would provide ten years of capacity for mill tailings wastes. Currently, solution from the aboveground impoundment is not recycled; however, the disposal pit plan will allow for the decant of solutions back to the mill or into the decant pond. This should decrease the freshwater usage at the mill.

T.2.16 Gas Hills Mill, Pathfinder Mines Corp.

The Gas Hills Uranium Mill (formerly the Luck Mc Mill) is operated by Pathfinder Mines Corp. (formerly Lucky Mc Corp.) in the Gas Hills region of Fremont, Wyoming, about 40 km (25 miles) northeast of Jeffrey City. This mill first began producing yellowcake in 1958 with a nominal ore-processing capacity of 850 MT per day. Since then the capacity has been expanded to about 2500 MT per day. The mill uses a two-stage acid-leach process and was the first in the United States to incorporate the moving bed ion-exchange technique originally developed in South Africa. It is also unique among U.S. uranium mills in using anion exchange for absorption of uranium from the feed solution.

Company-owned open-pit mining operations [1.5 to 3 km (1 to 2 miles) from the mill] supply 95% of the ore processed. The remaining 5% is produced at two underground operations--the West Gas Hills mine and the East Gas Hills mine. The ore grade has averaged 0.26% U_3O_8 in past operations and is expected to average 0.15% in the future. Although mines adjacent to the mill also could provide fresh water for ore processing, availability of hot [57°C (135°F)] well water at the site makes it advantageous from a process standpoint to use well water in the mill and to treat mine water for discharge.

The tailings retention system consists of five tailings ponds encompassing 55 ha (135 acres). The ponds are situated sequentially in a small natural ravine north-northwest of the mill and are dug into an underlying shale formation. Clay core dams keyed into the shale provide protection against lateral seepage. Only two of the five tailings ponds now contain tailings. The total tailings area of these two ponds is 28 to 32 ha (70 to 80 acres). The average tailings depth, now 11 m (36 ft), is expected to increase to 33 m (110 ft) by the end of milling operations (1996). The remaining three ponds are now used for solution evaporation.

In 1963, a flooding incident occurred at the mill site in which 8.7×10^7 L (2.3×10^7 gallons) of impounded tailings solution was released to the environment. This incident prompted an enlargement of the tailings impoundment to its current capacity. The existing system, with a minimum of 1.5 m (5 ft) of freeboard, is estimated to provide 8.7×10^8 L (2.3×10^8 gallons) of emergency storage.

T.17 Split Rock Mill, Western Nuclear, Inc.

The Split Rock Uranium Mill is part of Western Nuclear's operations in the Crook's Gap and Gas Hills Uranium Districts of Fremont County, Wyoming. The mill is 3.2 km (2 miles) north of Jeffrey City, Wyoming, at the base of several foothills of the Granite Mountains. The first uranium mill in Wyoming, the Split Rock mill began operations in 1957 with ore-processing capacity of 360 MT per day. Major modifications and modernizations in the process metallurgy have increased the processing rate to 1540 MT per day. About half of the mill's daily production comes from open-pit mines in the Gas Hills district and half from Western Nuclear's underground operations in the Crook's Gap mining district. The ore grade has ranged from 0.15% to 0.30% U_3O_8 during past operations and is expected to range from 0.05% to 0.15% in the future.

Tailings have been deposited in an area east to southeast of the plant since the beginning of operations. On April 12, 1977, tailings slurry escaped from the impoundment as a result of a breach in the embankment at the northwestern corner of the pond. About 10 m (33 ft) of the embankment was breached, resulting in a release of about 7.5×10^6 L (2.0×10^6 gallons) of tailings slurry.

For the estimated 20 remaining years of mill operation, a retention embankment will be incrementally constructed to a final elevation of 1964 m (6444 feet). The active tailings-disposal area now occupies 34 ha (85 acres). It is estimated that in 20 years the area occupied by the active and old tailings pond, dam, and embankment will have increased to a maximum of 93 ha (230 acres).

T.2.18 East Gas Hills Mill, Union Carbide Corp.

The East Gas Hills Mill is part of the Union Carbide Uranium Project in the southeastern portion of the Wind River Basin of Wyoming. The mill is about 95 km (60 miles) west of Casper, Wyoming, in an area of rolling hills interspersed with relatively flat areas.

The mill employs an acid leaching system (RIP-Eluex system) for recovery of uranium. Recycled solution from the impoundment system is used to wash sands after sand-slime separation. Additional pond decant solution is used for tailings dilution. The mill began operations in early 1960 with a capacity of about 1000 MT per day; in January 1980, the capacity was increased to 1250 MT per day. Open-pit operations at company-owned mines in East and West Gas Hills supply the ore. Sufficient ore is proven to maintain the current milling rate for five to ten more years. During the anticipated total active life of the project (1960-1986), about 12×10^6 MT (13×10^6 ST) of mill tailings will have been produced. The retention capacity [7.6×10^6 MT (8.4×10^6 ST)] of the mill's original above-grade tailings impoundment has been reached, and since January 1980, tailings have been discharged to a depleted open-pit mine with a capacity of 2.3×10^6 MT (2.5×10^6 ST). The pit has an area of 11 ha (26 acres), is clay-lined on the bottom, and has an in-pit dewatering system. The associated evaporation area consists of two ponds with a combined surface area of 9.7 ha (24 acres). A second mine pit will be available for tailings disposal in 1982. The maximum height of the embankment of the original abovegrade tailings pond (and expansions) is about 14 m (45 ft). The original retention system has an area of 60 ha (148 acres).

Union Carbide also operates a heap leach facility in the mill area at its East Gas Hills site. The water [1.7 L/s (27 gpm)] used in the process is taken from the A-9 pit, and U_3O_8 is recovered from the high-grade leach liquor by a solvent extraction process. The organic phase is pumped to the existing mill circuit. Union Carbide expects to recover 140,000 kg (310,000 pounds) of U_3O_8 from the low-grade ore.

T.2.19 Highland Mill, Exxon Corp.

Exxon's Highland mine and mill complex is in an area of rolling hills and stream valleys 97 km (60 miles) northeast of Casper, Wyoming, in the Powder River Basin. Exxon has been conducting mining and milling operations at the Highland location since 1972. The uranium ore processed at the mill is currently extracted from EXXON's surface mines and underground mine on the Highland property. The mill also produces uranium concentrate from solutions and slurries containing uranium recovered from tailings solutions, and from a pilot in-situ leaching process operated at Highland.

The Highland mill processes an average of 2720 MT per day of ore, but has attained levels as high as 2950 MT per day in recent operations. This is 50% more than the original design capacity when the mill opened in 1972. The increase was achieved primarily through mill modifications, such as changing electric motor horsepower ratings, altering process lines, and refinements and additions to instrumentation. Because of a high degree of automation in the plant, five workers can control the entire mill, which produces about 1800 MT (2000 ST) of yellowcake per year.

Tailings are contained in a natural valley enclosed by an earthen clay-core dam. The tailings pond covers an area of 80 ha (200 acres). The tailings surface slopes from both the west and east (embankment face) toward the pond. A small cutoff and pumpback system 210 m (700 ft) downstream of the embankment returns 3 L/s (50 gpm) of collected seepage to the pond.

T.2.20 Bear Creek Mill, Rocky Mountain Energy Co.

The Bear Creek Mill is part of a uranium project that includes open-pit mining operations in Converse County, Wyoming, about 72 km (45 miles) northeast of Casper. The site is in the southern portion of the Eastern Powder River Basin, between the Bighorn Mountains and the Black Hills. The site is located within the Thunder Basin National Grassland, consisting of intermingled Federal, state, and private land ownership.

Rocky Mountain Energy Co. dedicated its 900 MTPD Bear Creek complex on September 22, 1977. Production since has been increased to 1800 MT per day, a rate that will likely be maintained until 1990. U_3O_8 content of the ore ranges from less than 0.1% to 1.0%

The tailings impoundment is 300 m (1000 ft) west of the mill in a natural basin enclosed by an earth and rock dam. The dam will have a maximum height of 18 m (60 ft) and a length of 460 m (1500 ft). Embankment materials for the dam will come from borrow excavation of weakly cemented bedrock in mine pits.

The total area of tailings retention is [61 ha (150 acres). The average depth of tailings will be about 7 m (23 ft) by the end of 20 years of operation. The area is underlain by alluvium and claystone.

To improve stability, seepage through the tailings dam foundation will be controlled by excavating a cutoff trench to the top of the bedrock beneath the center of the dam and backfilling with impervious material. An additional measure to contain seepage from the tailings pond is the proposed construction of a 5-m (17 ft) (maximum height) dike about 240 m (800 ft) downstream of the tailings dam. Extending upstream from the dike's center will be a bentonite-filled trench reaching down to bedrock. Seepage collected in this trench will be pumped back to the tailings pond.

T.2.21 Shirley Basin Mill, Pathfinder Mines Corp.

Pathfinder Mines Corp. (formerly Lucky Mc Uranium Corp.) operates the Shirley Basin Uranium Mill in an area of plains and rolling hills about 72 km (45 miles) south of Casper, Wyoming.

Underground operations were used to mine the Shirley Basin property during the period 1960 through 1963; solution mining maintained production from 1963 through 1970. The mill was completed in 1971, and mining was converted to open-pit methods. The mill is autogenous, with no preliminary crushing. There are no conveyors in the plant. Static-bed resin columns extract uranium following acid leaching. The only recent change in mill equipment has been the installation of a new yellowcake dryer and the addition of a cyclone wash that washes sands through five successive cyclones in series. This addition increased mill throughput from 1090 to 1630 MT per day.

About 8.6×10^6 kg (19×10^6 pounds) of uranium concentrates will be produced over the 12-year lifetime of the mill. A tailings pile covering about 93 ha (230 acres) and containing 3.1×10^6 MT (3.5×10^6 ST) of tailings will be created. The impoundment system is unique in that wastes are segregated into two streams--a tailings slurry and overflow solution from yellowcake washing thickners. The tailings slurry is pumped to a tailings pond, where seepage control is provided by a compacted sandy clay blanket lining the pond bottom. There is no recycle from the tailings pond. Yellowcake thickener overflow is sent to a recycle pond, where it is mixed with cooling water and recycled to the grinding circuit. A collection ditch with a return pump returns about 0.6 L/s (10 gpm) of seepage to the impoundment system.

The present tailings pond covers about 61 ha (150 acres). It requires only a single-sided retention dam. The fill material for the dam and for the keyway consists of sandy clay excavated from the open-pit mine.

T.2.22 Shirley Basin Mill, Petrotomics

Petrotomics' Shirley Basin Uranium Mill is located in a hilly area about 77 km (48 miles) south of Casper in the eastern Shirley Basin area of Wyoming. The mill began operations in 1962 at the designed capacity of 480 MT per day; in 1967, new facilities were built to increase the capacity to 910 MT per day and to modify the solvent extraction circuit. In early 1975, Getty Oil and Skelly Oil acquired Kerr-McGee Nuclear Corp's one-half interest in Petrotomics. The mill was closed from 1974 until 1977 for refurbishing and process improvements. The mill now is processing ores from UJV (a joint venture of Getty and Skelly) and from the Jenkins Project of Utility Fuels, Inc. UJV holds properties in the Shirley Basin estimated to contain 6.4×10^6 MT (7×10^6 ST) of uranium reserves. At the present average processing rate of 1500 MT per day, the expected ore life is about 20 years.

The combined tailings slurry is pumped to a tailings area 140 m (450 ft) from the mill. The area was formed by damming a natural ravine with sand built up with mine overburden. The tailings dam is situated near the head of a small tributary drainage to Sand Creek. The tailings retention system currently consists of the main tailings pond [65 ha (160 acres)] and three catchment basins and emergency dams which collect and return lateral seepage or overflow from the tailings area. The tailings pond was constructed with an underlying layer of clay to reduce seepage. The capacity of the tailings pond has been reached and Petrotomics has constructed an addition to the existing dam. The embankment addition was constructed downstream of the existing embankment, incorporating the existing embankment in the upstream toe of the larger embankment.

T.3 REVIEW OF URANIUM MILL TAILINGS MANAGEMENT PROGRAMS INVOLVING BELOW-GRADE DISPOSAL

Speech presented by:

Ross A. Scarano, Chief
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U.S. Nuclear Regulatory Commission

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REVIEW OF URANIUM MILL TAILINGS MANAGEMENT PROGRAMS INVOLVING BELOW GRADE DISPOSAL

Ross A. Scarano, Chief
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It wasn't until late 1976 that the U. S. Nuclear Regulatory Commission (NRC) set about to address the uranium tailings issue in earnest. It was decided that a generic environmental impact statement related to uranium milling operations would be prepared to support formal tailings regulation. We recognized, however, that this was a task that would take many years to complete and we could not take a "business as usual" approach to tailings management in the interim; the issue was too sensitive. To facilitate licensing during the interim period, the NRC developed guidelines in May 1977, for the industry in the form of the following performance objectives for tailings management:

<u>Siting and Design</u>

1. Locate the tailings isolation area remote from people such that population exposures would be reduced to the maximum extent reasonably achievable.
2. Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.
3. Design the isolation area such that seepage of toxic materials into the groundwater system would be eliminated or reduced to the maximum extent reasonably achievable.

<u>During Operations</u>

4. Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

<u>Post Reclamation</u>

5. Reduce direct gamma radiation from the impoundment area to essentially background.

6. Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.
7. Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation plan.
8. Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan.

As can be seen, the objectives were tailored to allow industry flexibility in developing tailings management alternatives for specific sites.

In the last few years many innovative schemes have been developed through the licensing process in order to meet these objectives. These tailings management programs, developed through NRC/Industry negotiations coupled with the research studies performed for the generic statement, have resulted in rapid advances in the state-of-the-art.

While the licensing program continued on a case by case basis, the NRC prepared and issued the draft environmental impact statement (GEIS) on the U. S. uranium milling industry in April of 1979. In August of 1979, regulations incorporating conclusions of the GEIS and of recent U. S. legislation on uranium mill tailings were issued for public comment. While the scope of the GEIS was very broad, the draft GEIS and the associated proposed rules focus primarily on the technical and associated institutional aspects of isolating the very long term hazards of the uranium mill tailings.

The public interest in the GEIS and associated rulemaking has been extensive. We held two public meetings during the comment period and received over 100 letters of comment. In reviewing public comments, we have not found a basis for changing to a large degree the proposed regulations. We expect to issue the Final GEIS and mill tailings regulations in late 1980.

Following are some examples of below-grade tailings management programs that have been authorized or are in final review. While these programs have been developed by the industry and reviewed by the NRC using the 1977 tailings management performance objectives, we feel that these programs, with minor variations at most, will also meet the forthcoming tailings regulations.

Union Carbide - Gas Hills, Wyoming

The Union Carbide Corporation (UCC) uranium mill is an existing facility located in the Gas Hills mining district in Natrona County, Wyoming. A new tailings disposal plan (Figures 1 and 2) involves the deposition of tailings below-grade into an existing mined-out pit (designated the A-9 pit) with a clay lined bottom and an inplace tailings dewatering system that is designed to minimize seepage. Use of this pit disposal scheme essentially eliminates the 100 gpm of seepage from the existing tailings impoundment and minimizes the height and area of above-grade tailings to be reclaimed upon cessation of operations.

The new disposal plan involves grading of the bottom of the A-9 pit, approximately 26 acres, to provide a slope to the south as well as to the center line and placing a three (3) foot compacted clay liner along the total graded pit bottom surface.

The inplace dewatering system for the pit consists of three major parts: (1) A filter blanket system covering a perforated collection line starting at the north end of the clay lined bottom and extending southward along the pit center line. An additional filter blanket extending along the pit's south wall where the collected liquids from these filter blanket systems discharge into a collection sump. The pit's bottom has been designed to converge to one common point in the south end of the pit. At the convergence, a depression serves as a gravel collection sump. (2) Four well casings with submersible pumps remove the accumulated water for transfer to evaporation ponds. (3) A contingency of three decant lines will be available in the event that the filter blanket system cannot remove the total volume of free tailings liquor. All three lines can collect liquor from separate locations within the pit, all draining to the collection sump well casings.

Tailings slurry will be discharged so that slimes will be forced to the side walls of the A-9 pit and provide sealing of the side walls. Discharge will be such that the filter drainage blanket will be covered with sands from the tailings slurry. As slimes approach the center drainage blanket, tailings slurry will begin to be discharged from the center ramp. Results of calculations for the below-grade impoundment with inplace dewatering indicate an average seepage rate that could range from 13 gpm to a conservative estimate of 33 gpm.

Liquor from the dewatering systems will be transferred to two new clay-lined evaporation ponds with a nominal surface area of 24 total acres. The ponds will be located adjacent to the west side of the A-9 pit on a

mine spoil pile and will serve three purposes: (1) to provide additional surface area for evaporation of excess liquor so that the water balance can equalize, (2) to provide surge capacity for excess liquor during the winter months when there is no evaporation, and (3) to provide a storage area for liquor to be recycled to the mill.

There will be some seepage from the evaporation ponds. However, the staff has calculated that the impacts are minimal with the maximum seepage approximated at 35 gpm with the maximum extent of seepage at approximately 30 feet during the pond's lives.

The post reclamation phase performance objectives of: (5) Reducing direct gamma radiation from the impoundment area to essentially background, (6) Reducing the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs, (7) Eliminating the need for an ongoing monitoring and maintenance program following successful reclamation, will be met based on the proposed reclamation plan. Five and six will be met by the fact that an adequate depth of suitable cover material will be placed over all tailings (At least one foot of clay and 10 feet of overburden near the south end of the pit and 20 feet toward the north end). Filling in the A-9 pit to the natural grade level and blending the cover material into the natural contours will ensure that the seventh performance objective is met. After the pit is filled in, there would be no additional mound of tailings to impact on the landscape and be subject to erosion. Long-term stability of the below-grade tailings and the need for no ongoing monitoring and maintenance would be readily assured.

Sweetwater - Sweetwater County, Wyoming

The Sweetwater Uranium Project (expected to be operational by August, 1980) is located northwest of Rawlins, Wyoming in the Red Desert area of the Great Divide Basin. The tailings from the milling operation will be discharged by a slurry pipeline to a 4-cell impoundment (Figures 3 and 4) Each cell will be excavated above the water table and will be lined on the bottom and on the interior dam slopes with a PVC liner. The cells will be constructed as individual units, and construction of each successive cell will take place as necessary to meet ongoing tailings storage and water evaporation requirements. The dam confining each cell will be designed as a zone structure. The entire impoundment will have sufficient storage and evaporative capacity to service the mill over its full life. The total area covered by the impoundment will cover about 300 acres (120 ha), and the internal area containing the mill tailings would cover about 250 acres (100 ha).

The proposed dam which will prevent surface runoff from entering the pond and provide an evaporation pond for the liquid portion of the tailings will consist of a central core of low permeability, a previous downstream shell, and a random fill upstream shell. The dam will be designed to be structurally independent of the synthetic liner and its integrity not dependent on the presence or effectiveness of the liner.

Inside slopes of each cell will be constructed with a horizontal to vertical ratio of 3:1. Slopes on the exterior will be constructed to 2:1, with an intermediate 15-foot (4.6-m) wide bench 20 feet (6 m) below the dam crest.

The synthetic membrane will consist of 30-mil thickness PVC (polyvinyl chloride) material applied to the bottom of the cells and a 30-ml reinforced Hypalon liner to the interior sides of the cells.

Following the completion of active milling and after a postoperational drying period sufficient to provide a competent working surface, the tailings will be covered with selected overburden, 10 to 14 feet (3 to 4.2 m), from the above-grade dams and suitable topsoil. Any excess overburden from the above surface dams will be spread over disturbed mining areas during reclamation. The cover mantle overlying the entire tailings impoundment area will be contoured to essentially pre-project levels with a reclaimed slope of approximately 100:0.25.

White Mesa - San Juan County, Utah

The site of the White Mesa Uranium Mill (expected to be operational in June, 1980) is in San Juan County in southeastern Utah. The area within an 8-km (5 mile) radius of the mill is sparsely populated (70 - 80 people) and primarily agricultural. The closest currently inhabited dwelling unit is approximately 5 km (3 miles) north of the site.

Approximately 350 acres (142 ha) of the site are to be used for a six-cell tailings impoundment system (Figures 5 and 6). The tailings cells are constructed by excavating the bottom of a natural swale and placing a series of embankments across the swale to form the downstream sides of each cell.

The tailings system features simultaneous construction, operation, and reclamation of sequential cells. While a filled cell is dried and reclaimed, the next cell downstream is filled with tailings, and a third cell is constructed and lined.

To minimize seepage of liquid wastes from the impoundment, the operator will line all interior surfaces of each cell with a 30 mil PVC liner. A subdrain will be installed on the downgradient side of the cell below the PVC liner.

Reclamation will be staged as each cell dries. Cover includes a 2-foot compacted clay cap with an additional 12-ft local soils. Reclaimed slopes will be no steeper than 6H:1V and would be covered with riprap.

Morton Ranch - Converse County, Wyoming

A series of mined out pits adjacent to the mill will be used for disposal of slurried tailings (Figures 7 and 8). These pits would provide approximately 93.9 acres (38 ha) of pit area with a storage capacity of 6.977 x 106 m^3 over the projected 20-year life of the mill. The pooled liquid would be decanted from the pits. That portion not returned to the mill circuit would be routed to an evaporation pond with a surface area of approximately 110 acres (44 ha), i.e., area necessary after 20 years of mill operation.

The use of pits for tailings retention would require the sealing of the floor with compacted clay and backfilled above the water table.

Initially the operator planned to line the pit walls with clay, however, both the operator and the NRC are leaning to an in-pit dewatering system as a better option to minimize seepage impacts.

The pit areas will be reclaimed to the natural contours with at least 12 feet of cover materials over the tailings.

Mt. Taylor - San Mateo, New Mexico

The Mt. Taylor project proposes a more complex tailings management system that includes a parallel series of dragline excavated trenches for burial of tailings solids, a slimes settling pond(s), and an evaporation pond (Figures 9 and 10). The plan calls for trench burial of 50 percent (13 million tons) of the produced tailings with the remaining 50 percent (comprised of tailings sands) used as deep mine backfill.

The first tailings trench or "box cut" would be excavated the approximately one-half mile length within the trench area boundary and the excavated material (spoil) would be stockpiled beside the cut. Each trench would be approximately 75 feet wide at the bottom, 125 feet wide at the surface, and 50 feet deep, and would have a gradual slope at the bottom of less than one percent. The trenches would be excavated into relatively tight bedrock units of predominantly shales and siltstones and which have low permeabilities.

The tailings would be transported to the burial site through a six-mile pipeline from the mill at approximately 20 to 40 percent solids by weight. The tailings slurry would be discharged at the elevated end of a trench and gravity separation of the sands and slimes would occur. Berms would be constructed at intervals along the trench bottom to promote settling of slimes. In this manner, sand beaches would eventually cover and consolidate the slimes. The pooled raffinate behind the berms would be pumped to the intermediate slimes settling pond. Clear water from the slime pond would be pumped to the evaporation pond.

As each succeeding parallel trench cut is made, the spoil would be deposited on top of the drained tailings placed in the previously filled trench to a level five feet below the existing ground level. The reclaimed trench area would have a 50-foot cover and be contoured to about 8 H:1V slopes.

The operator proposes to line both the slime and evaporation ponds with three feet of compacted clay to minimize seepage impacts. The final method of seepage controls utilized for this project is still an open issue between the operator and the regulatory agency. The slimes settling and evaporation ponds would cover about 200 acres.

Pioneer - San Miguel County, Colorado

Pioneer Uravan's San Miguel project is proposed to be located in Disappointment Valley, Colorado approximately 6 km east of Slick Rock and 5 km east of the nearest resident. The Pioneer tailings management plan (Figures 11 and 12) proposes disposal of dewatered tailings in a series of below grade trenches. The filtered tailings will move by conveyor from the mill to the trenches dug adjacent to the millsite. Each of the 10 trenches will be 250 feet wide, 2500 feet long and 30 feet deep. The total impoundment area is 172 acres. Since the tailings are expected to be 20-25 percent moisture by weight and the trenches will be placed in a relatively impermeable Mancos Shale formation, seepage impacts are expected to be minimized. Liquid wastes will be disposed of in two clay lined evaporation ponds of approximately 130 acres total.

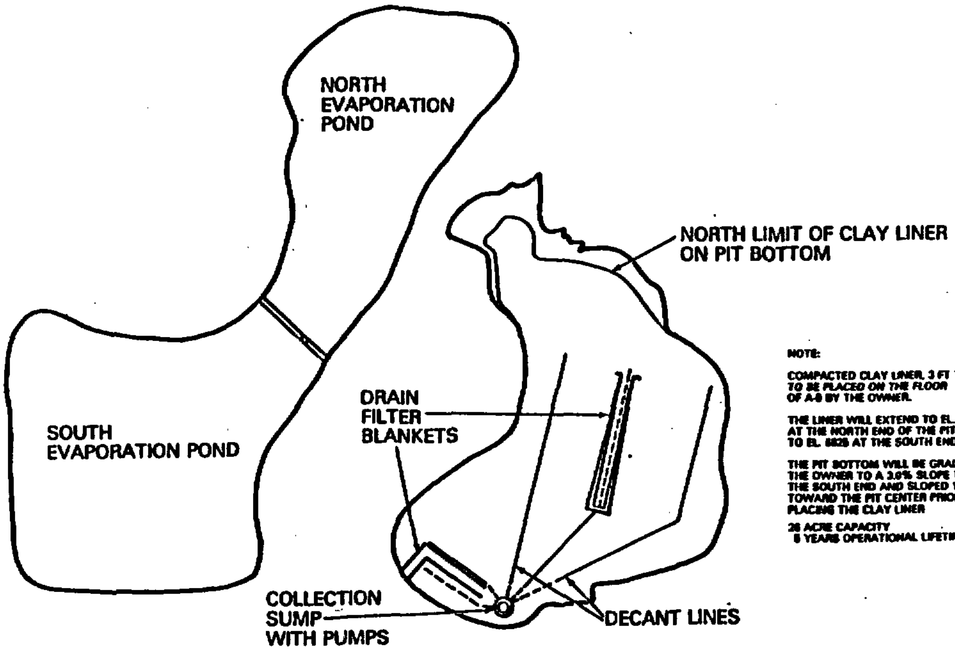
Excavation, operation and reclamation of the trenches will be phased during the 20-year lifetime of the mill. The reclaimed tailings area will be covered with a three-foot compacted clay cap and 17-20 feet local soils. Side slopes will be gentle and top covered with 12 inches of riprap.

As can be seen by these examples of tailings management programs, there are recurring program elements that are finding favor by operator and regulator alike. These are:

1) Tailings dewatering systems
2) lined evaporation ponds
3) staged systems
4) reclamation consisting of abundant cover material and gentle slopes
5) riprap as a final cover

I am confident that continued effort by the industry in developing methods to resolve specific problems related to tailings will result in a longer list of acceptable program elements. Then a prospective mill operator can select elements from this pool to fit individual site and process characteristics.

GAS HILLS—BELOW-GRADE TAILINGS DISPOSAL



NOTE:

COMPACTED CLAY LINER, 3 FT THICK TO BE PLACED ON THE FLOOR OF A-9 BY THE OWNER.

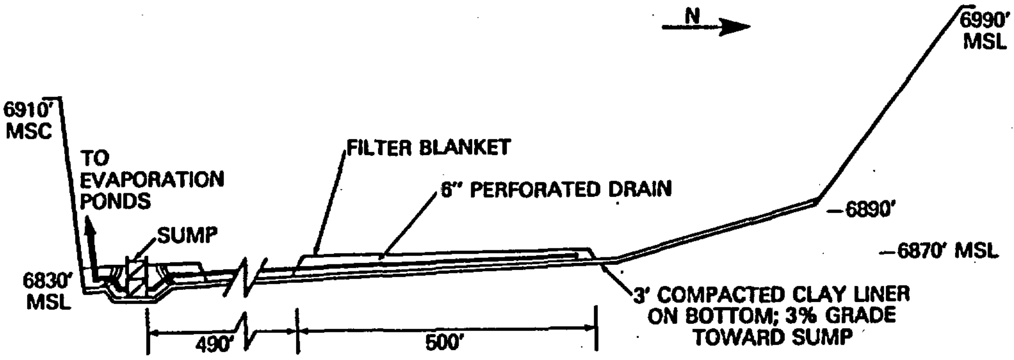
THE LINER WILL EXTEND TO EL. 6890 AT THE NORTH END OF THE PIT AND TO EL. 6828 AT THE SOUTH END.

THE PIT BOTTOM WILL BE GRADED BY THE OWNER TO A 3.0% SLOPE TOWARD THE SOUTH END AND SLOPED 1.0% TOWARD THE PIT CENTER PRIOR TO PLACING THE CLAY LINER

26 ACRE CAPACITY
5 YEARS OPERATIONAL LIFETIME

Figure 1

UNION CARBIDE GAS HILLS URANIUM FACILITY A-9 PT



PIT AREA ~ 26 ACRES
VOLUME ~ 2.5 × 10^6 TONS OF SOLID TAILINGS
OPERATIONAL TIME ~ 5 YEARS

Figure 2

SWEETWATER PLOT PLAN OF TAILINGS PITS

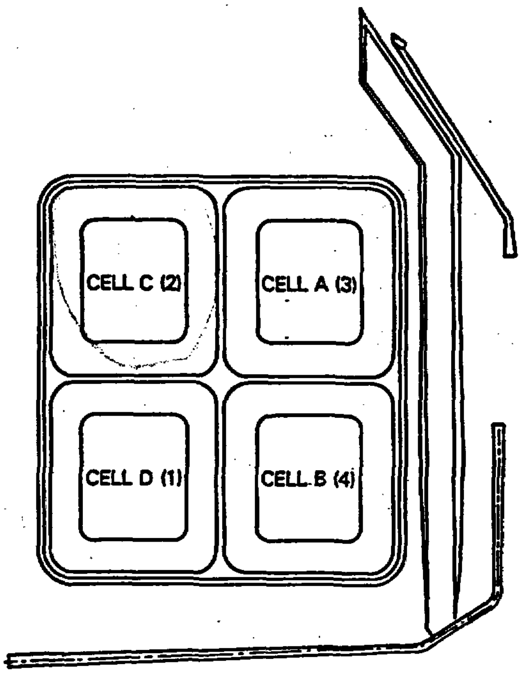


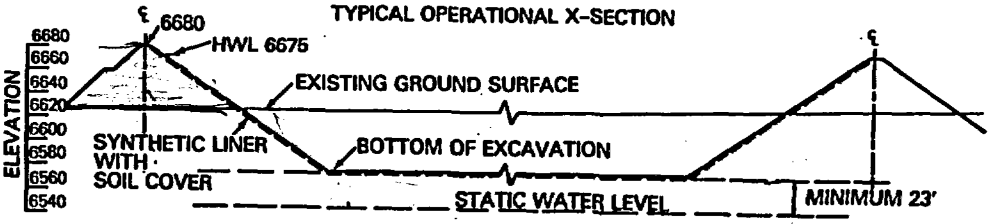
Figure 3

SWEETWATER CROSS SECTIONS OF TAILINGS CELL

TYPICAL OPERATIONAL X-SECTION

6640

6625



TYPICAL FINAL RECLAIMED X-SECTION

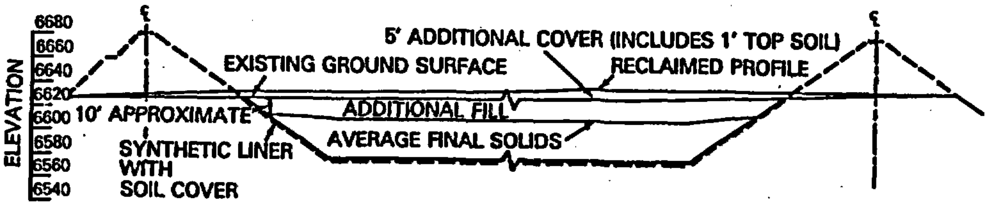
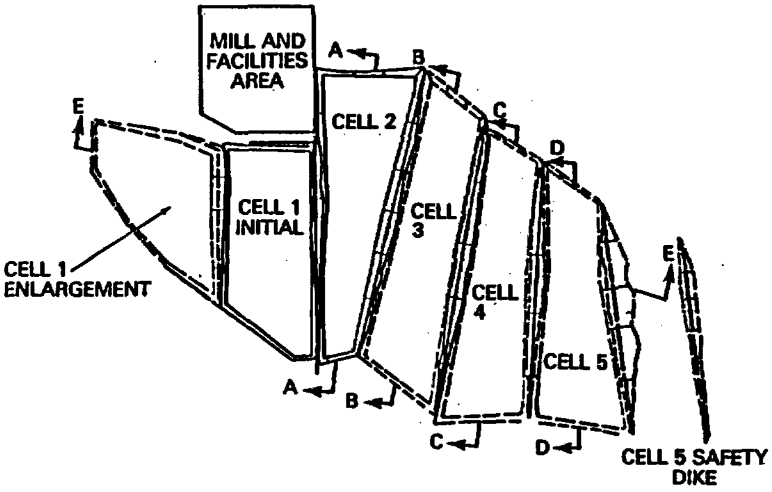


Figure 4

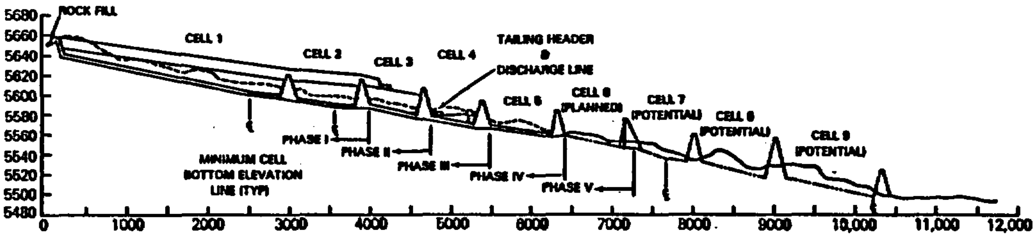
ENERGY FUELS—SIX-CELL TAILINGS DISPOSAL SYSTEM



WHITE MESA PROJECT

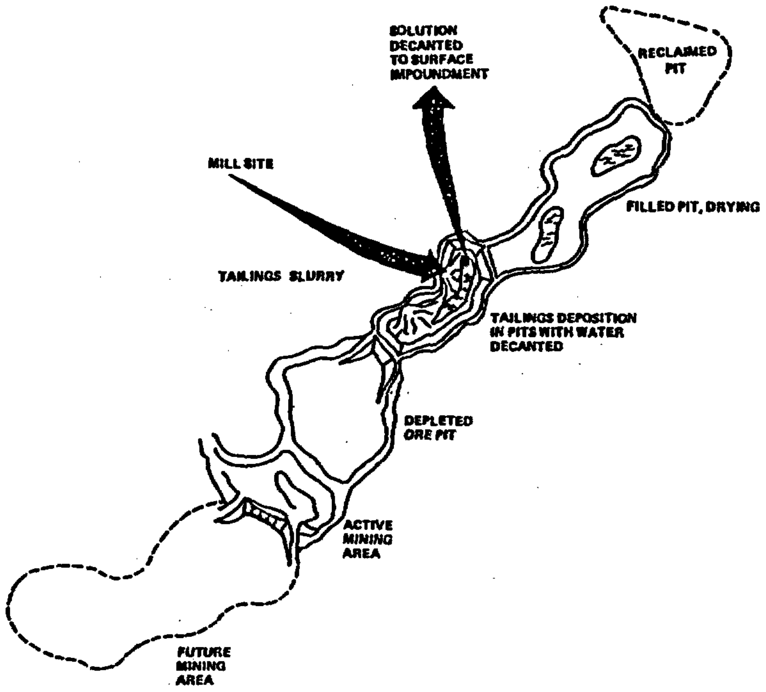
Figure 5

SELECTION A—A
6—CELL TAILING DISPOSAL SYSTEM
YEAR 9



WHITE MESA PROJECT

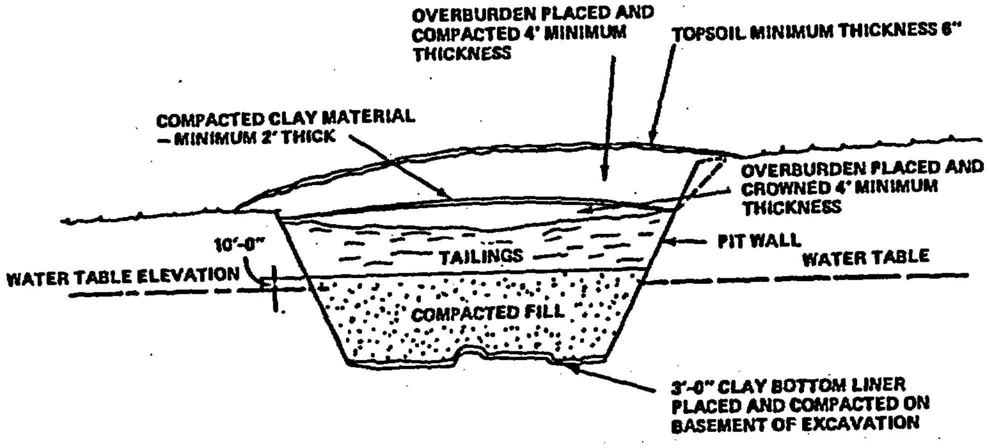
Figure 6



STAGED TAILINGS IMPOUNDMENT IN AN ACTIVE OPEN PIT MINE

MORTON RANCH PROJECT

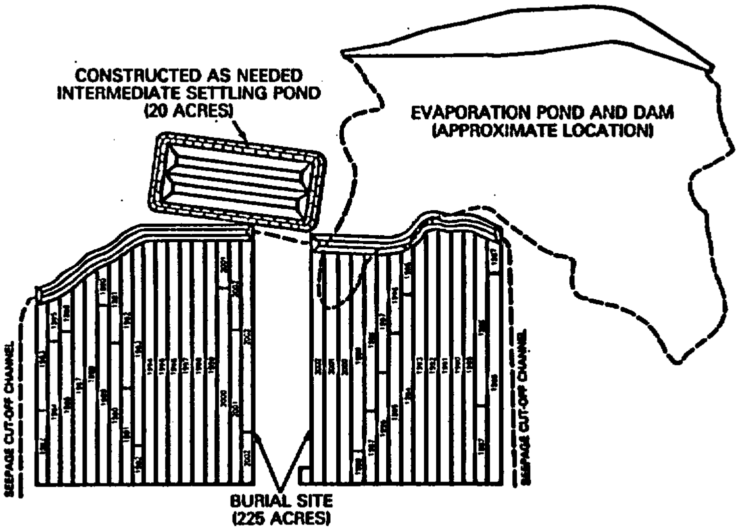
Figure 7



MINED-OUT PIT BURIAL DEWATERED TAILINGS

MORTON RANCH PROJECT

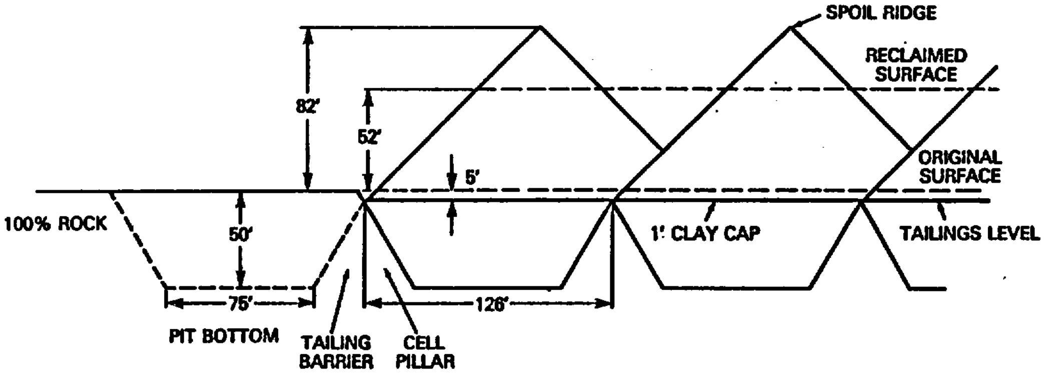
Figure 8



MT. TAYLOR PROJECT

Figure 9

GULF—TRENCH CROSS-SECTIONS



MT. TAYLOR PROJECT

Figure 10

PIONEER—TAILINGS IMPOUNDMENT PLAN

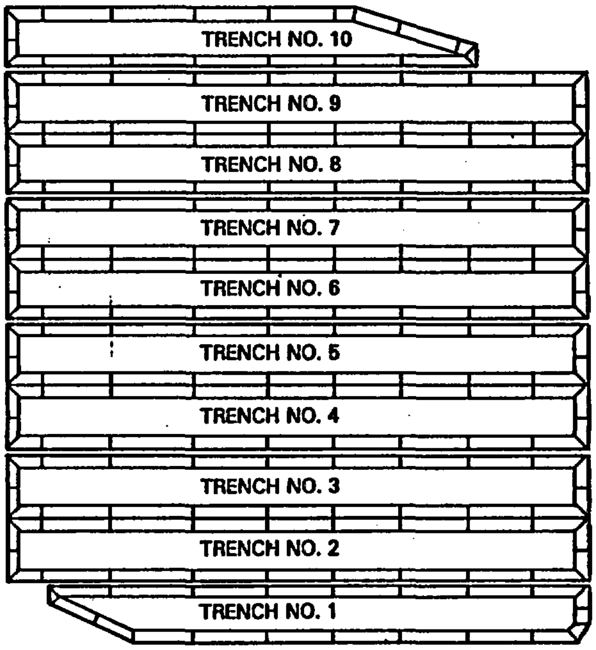


Figure 11

PIONEER—CROSS SECTION THROUGH IMPOUNDMENT

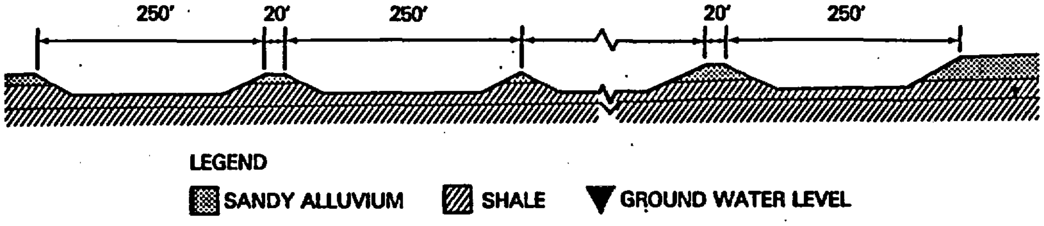


Figure 12

APPENDIX U. COST-BENEFIT CONSIDERATIONS FOR POST-RECLAMATION RADON FLUX

1. INTRODUCTION

The staff has evaluated the matter of long-term tailings radon flux control in terms of a wide range of public health and cost factors. Alternative radon release limits have been evaluated in terms of the following factors: costs for applying a final tailings cover under a full range of conditions such as will occur with varying ore grades, impoundment sizes and shapes, cover material types and so on; impacts on maximum exposed individuals as they compare with existing radiation protection standards; total population exposures as they compare with population exposures from natural and technologically enhanced radon releases, both short and long term; and, radon fluxes that occur from natural soils. The specific cost-benefit analysis of the radon control question is presented in Section 12.3.4.

In doing the cost-benefit analysis in Chapter 12, the staff considers it has conformed to the applicable guiding principles for radiation protection are those established by the International Commission on Radiation Protection (ICRP). These may be summarized as follows:[1]

a. No practice shall be adopted unless its introduction produces a net positive benefit (justification of the practice).

b. The resulting dose equivalents to individuals shall not exceed the limits recommended for such doses under the appropriate circumstances (limitation of individual risk).

c. All exposures shall be kept "as low as reasonably achievable" (ALARA) taking into account economic and social factors (optimization of radiation protection).

Application of the first principle involves making a judgment as to whether or not the particular enterprise considered yields a net overall benefit, all things being considered, and is thus far too broad to apply to the limited issue of post-reclamation radon control and is clearly beyond the stated purpose and scope of this study (42 FR 13874). This study has not considered the question of whether there should be uranium milling or not. This is decided when reactors are licensed. The second principle is indeed applicable, and is considered in Sections 12.3.4.3 and 9.4.2 of the main document. In general, residual radon releases yield relatively small individual doses and are thus more limited by consideration of aggregate population risks.

The staff considers that in its cost-benefit evaluation of Chapter 12, it has established what is ALARA as far as radon control and tailings containment is concerned. Another manner of applying the third principle might be to identify as the most appropriate control level that level at which the costs of any further control exceed the incremental benefits that would be derived. This control level is theoretically determinable by employing an analytical technique referred to here as "optimization" although it is perhaps more widely known as cost-benefit balancing. Radiation risks can usually be reduced to successively lower and lower residual levels by the application of additional controls. However, as residual risks become smaller and smaller the costs of further control, when expressed as a cost-benefit ratio (dollars spent per unit risk averted), become larger and larger. The process of optimization is used to determine that control level at which further control is no longer justified.

This optimum control level may also be equivalently defined as that level at which the aggregate societal "costs" of applied control and remaining risk are minimized, i.e., total costs of control and residual risk are higher for any different control level whether it be lesser or greater than this optimum level.[2,3] Although optimization is an elegant, simple and exacting concept it can be extremely problematical in actual use. Severe difficulties can be encountered in the process of attempting to precisely quantify and express in like units all involved costs and risks. Despite these difficulties, the staff examined the applicability of the optimization concept to the problem of long-term radon control. This appendix documents this examination, the results obtained, and the conclusions reached.

2. BASIC METHODOLOGY

A complete cost-benefit optimization involves an analysis of the costs of providing protection (C_p) and the residual impact to society or detriment which, when valued as a cost, is denoted by

C_d. With C_p and C_d both being expressed in like units, the combined costs of control and residual detriment may then be denoted by C_t where:

$$C_t = C_p + C_d \tag{1}$$

Cost-benefit optimization is achieved by that level of control which minimizes C_t.[2-4] This approach assures that total costs would be higher at any other level of control.

Optimization involves analysis on an incremental or differential basis to assess the cost-effectiveness of any further control as opposed to the overall cost-effectiveness of all applied control. Optimization thus reflects the cost-effectiveness of small adjustments about some particular level of control. Mathematically, total costs as given by C_t in equation 1 are minimized when the first derivative has the value of zero. This condition is expressed by:

$$\frac{dC_t}{dF} = \frac{dC_p}{dF} + \frac{dC_d}{dF} = 0 \tag{2}$$

where F denotes the radon flux from the reclaimed tailings (pCi/m^2-sec).

In order to make use of equation 2, C_p and C_d must be expressed in closed form as continuous functions of F. Once this is accomplished the optimum flux (F_{opt}) associated with the optimum control level is determined simply by solving equation 2. It is the first step, rather than the latter, wherein substantial problems arise. In order to avoid the many inherent difficulties involved in a fully rigorous analysis, a somewhat simplified calculational approach is adopted and discussed below. Simplifying assumptions include assuming constant conditions of atmospheric dispersion, population density, surface radon flux, value of life, etc. Uncertainties and errors introduced via such assumptions are discussed later.

As assumed in Section 6.4 for a constant population at risk, the health detriment arising from radon releases at a given surface flux may be expressed by:

$$D = A_1 F \tag{3}$$

where A_1 is a constant conversion factor, F is the surface flux, and D is the annual health detriment arising from continued radon releases (premature cancer deaths per year). The units of A_1 are thus health effects per year per pCi/m^2-sec.

As shown in Chapter 11 and Appendix K, the costs of providing radon control, by installing an earthen cover of thickness x meters, may be expressed as:

$$C_p = A_2 + A_3 x \tag{4}$$

where C_p is the total dollar cost; A_2 is the fixed dollar cost of final contouring, surface stabilization by rock cover or self-sustaining vegetation, and other costs not proportional to cover thickness; and A_3 is the dollar cost per meter thickness of applying earth cover.

As indicated in Appendix P, the relationship between cover thickness and surface radon flux can be approximated by:

$$F = F_o \exp(-A_4 x) \tag{5}$$

where A_4 is a function of the correction factor h, which is in turn dependent on the cover thickness x. For simplicity, an average value of h is used here so that A_4 will be a constant independent of x. Also, the assumption made in this analysis is that x will remain constant with time--that is, it is assumed that there will be no erosion or aggradation at the site. Under these assumptions, equation 5 may be solved for x and substituted into equation 4 to obtain

$$C_p = A_2 + (A_3/A_4) \ln (F_o/F) \tag{6}$$

Having expressed the costs of radon control in dollars and as a function of the residual flux F, it is now necessary to do the same for the health detriment C_d. Equation 3 relates the annual health detriment D, in units of health effects per year, to the residual surface flux F. The total health detriment, D_t, is obtained by integrating the annual health detriment D over time. For our purposes it may be assumed for the present that D is a constant and does not vary with time. Under this assumption, D_t is given by:

$$D_t = \frac{80{,}000}{0.693} D + 0.07 \frac{4.5\text{x}10^9}{0.693} D \tag{7}$$

where: 80,000 is the halflife of Th-230 in years;

4.5×10^9 is the halflife of U-238 in years;

0.07 is the fraction of U-238 in feed ore which is passed through with the tailings; and

0.693 is the natural log of 2.

Equation 7 includes integration of all radon releases over the full lifetime of the uranium and thorium progenitors. The radon released due to the initially present inventory of Ra-226 is temporarily disregarded due to its relative insignificance. Equation 7 results in a value of D_t which is 4.5×10^8 times the value of D. The constant 4.5×10^8 represents the effective number of years over which health effects at the constant annual rate D are integrated to arrive at the total health detriment D_t, and may thus be modified to consider shorter time periods. The value of C_d is obtained by multiplying D_t (health effects) by A_5, a constant representing the dollar value of a health effect. Substitution into equation 3 then yields:

$$C_d = 4.5 \times 10^8 A_1 A_5 F \quad (8)$$

Equations 6 and 8 may then be substituted into equation 2 and solved for F to obtain F_{opt} as given by:

$$F_{opt} = A_3/(A_1 A_4 A_5 T) \quad (9)$$

where T is the effective number of years of annual health effects at the rate D which are included in the calculation. (The maximum value of T is given by equation 7 as 4.5×10^8.) The theoretical optimum flux can thus be obtained by substituting appropriate numerical values for the constants denoted by A_1, A_3, A_4, A_5, and T in equation 9. It should be noted that the parameter A_2, which reflects the costs of surface erosion protection, is no longer involved due to the differentiation step involved (see equation 2). Although F_{opt} is apparently independent of A_2, a constant surface flux--that is, constant x in equation (5)--could not in reality be maintained without adequate surface erosion protection. As discussed more fully below, the cost of such protection will normally be greater than costs of initial tailings cover, A_3, and will even be much more significant in determining what the cover thickness, x, will be over the long term. Although the ongoing value of x is actually more dependent on A_2 than A_3, the vast uncertainty about the exact relationship between A_2 and x make it impossible to explicitly include this dependence in this analysis.

3. NUMERICAL APPLICATION

In order to determine the optimum radon flux control limit using equation 9 numerical values must be assigned to the various involved constants. These are defined as follows:

A_1 = the annual health effects resulting from radon releases at a constant surface flux, health effects per year per pCi/m^2-sec;

A_3 = the cost of applying earth cover, dollars/meter;

A_4 = the constant a_1 appearing in equation 2 of Appendix P, m^{-1};

A_5 = dollar cost per health effect; and

T = the effective number of years of annual health effects at the rate D which are weighed in the calculation.

Values for these parameters are discussed briefly below, on an individual basis. Although not incorporated in equation (9), the fixed cost parameter A_2 is also discussed because of its paramount importance in determining actual long-term tailings performance. The above values are each evaluated on the basis of 76 model mills, each with 80 ha (200 acres) of buried tailings produced by processing 0.1% U_3O_8 ore. Health effects are based on the constant population assumed to exist as of the year 2100 and include both regional and continental components. Cost estimates for earth cover and health effects are based on current costs assuming future inflation or deflation would affect both equally. Uncertainties are considered in some detail, but not in depth.

3.1 Parameter A_1. Section 6.4 of this document indicates that approximately 6 cancer health effects per year would result from a surface flux of 280 pCi/m^2-sec, based on population distributions expected by the year 2100. This yields a value of 0.021 effects/yr per pCi/m^2-sec not including genetic defects and also not including effects due to exposure outside North America (an additional 25%).

Many subordinate factors are involved in this parameter including atmospheric dispersion, population densities, living habits, biological factors, and health risk coefficients. The health risk coefficients utilized are those discussed in Appendix G-7 and are based on an assumed linear, no-threshold dose-effect relationship. Although this assumption may indeed be valid, or even underestimate resulting health effects, presently available epidemiological data do not conclusively rule out the possibility of zero effects at the individual low doses and dose rates involved here (conclusive evidence does exist with respect to the induced occurrence of lung cancer at the higher radon doses and dose rates encountered in underground mines). Therefore, the ultimate lower bound for the value of A_1 is taken to be zero. For illustrative purposes, downward variability by a factor of 10 is considered.

With respect to higher values, A_1 is dependent on assumed population densities which have considerable potential upward variation. Over the relatively recent past the population of the world, and North America in particular, has increased dramatically. It is possible to have much larger populations and population densities within the next several hundred years than are presently projected for the year 2100. The projected population within 50 miles of current mills even now ranges to a factor of 10 larger than that assumed to exist in the model region. Given these uncertainties, and uncertainties of other factors, the value of A_1 is considered to have a nominal upper limit of 10 times the value derived from Section 6.4, or 0.21 health effects/yr per pCi/m^2-sec.

3.2 Parameter A_2. The factor which will determine what the releases of radon will be over the long term is not the initial thickness of radon attenuating cover placed over the tailings (the cost of which is A_3). It will be a complex function of chiefly climatic and topographic site-specific conditions and of those siting and design features which are built into a disposal program to account for these conditions. The siting and design features include such things as placing tailings below grade, flattening of slopes, minimizing of upstream drainage, providing cover erosion protection, and so on, which are intended to isolate the tailings containment from erosion and other disruptive processes. Parameter A_2, the cost for these factors, will vary widely from site to site (Section 12.3.3). Also, there is no practicable way to correlate each of these steps with specific levels of long-term performance. What will be the increase in containment effectiveness over hundreds or thousands of years of providing slopes that are 10h:1v as opposed to 2h:1v? or of having rock cover over exposed slopes of embankment as opposed to vegetation alone? What will be the difference in tailings cover erosion over hundreds or thousands of years, if there is an upstream drainage area of a square mile with a 1% grade at a site as opossed to a few acres with a 5 percent grade? Or, if there is a few more inches of net rainfall per year at one site than at another? These differences are significant in terms of actual radon releases, but they are impossible to quantify.

The overriding importance of parameter A_2 over parameter A_3 is reflected in the rejection of the tailings disposal mode (so-called Active Care Mode) where a cover is placed over the tailings but no measures are taken to prevent degradation of the tailings cover. This is stated as a major conclusion of this statement in Section 12.3.3. Cost for protective measures (A_2), as described in 12.3.3 and line item 1 in Table 12.1, range from less than half cover costs to nearly four times more.

3.3 Parameter A_3. As indicated by data presented in Appendix K, unit costs for applying earth cover are expected to be approximately \$1.4M per meter of cover for the model mill and range from about \$1.0M to \$4.2M, a factor of 3 higher. For 76 model mills the estimated cost would be \$106M, ranging from about \$76M to \$320M. Greater variability is possible.

3.4 Parameter A_4. Consideration of the data presented in Appendix P yields an estimated typical value of about 1.3 with a range of from 0.8 to 3.0. The higher value corresponds to cover material with a much higher than average moisture content.

3.5 Parameter A_5. The monetary value of a human life is a highly judgmental quantity. To most people, even the idea of establishing a dollar value for life is truly repugnant. Nevertheless, judgments as to the value of life are implicitly made on a continuing basis in the course of every day existence. For example, families may vacation by car rather than plane in order to save money, despite the increased risk of fatal accident. Some indication of what society is willing to spend today to avert a health effect today can be obtained by examining what society is spending to reduce risk from other life-threatening hazards. This ranges widely, however, depending upon many complex societal factors and perceptions--anywhere from as little as \$20,000 to at least \$10,000,000 per health effect saved and more has been spent on health protection.[6] This range includes expenditures for such things as medical screening and care, automobile traffic safety, airline safety, radioactive and nonradioactive-related emissions and activities.

Expenditures for radioactivity-related risks are routinely much greater than for other societal risks. The estimated average value assumed here for A_5 is $0.4M which is within the range cited above.

3.6 Parameter T. This parameter is the effective number of years of health effects occurring at the annual rate D which are weighed in the calculation of optimum flux. The ultimate upper limit of the value of T is given by equation 7 as 4.5×10^8; it results almost entirely from radon produced following decay of U-238 with a 4.5 billion year half-life. The radon produced following decay of the 7% of the uranium in the ore passed through the mill as waste would not become a significant fraction of total radon releases for about 100,000 years, at which time it would amount to about 14% of total radon emissions. Therefore, if consideration of health effects occurring only within the first 100,000 years is desired, the U-238 component could be safely discarded with no great sacrifice in precision (especially given other larger uncertainties).

Over the first 4.5 billion year half life of U-238 gradually occurring processes could reasonably be expected to largely redistribute all materials now present in the earth's crust (this time period exceeds the historical age of any known life form). Therefore, steps taken now to isolate tailings wastes would be wholly inconsequential, i.e., they would not affect total radon releases to the biosphere one way or another. During this time interval the radon released from minable uranium resources would be independent of whether the uranium was mined or not. Therefore, no value can be assigned to earthen reclamation cover with respect to control of radon releases from U-238 and impacts from such releases could not justifiably be debited against the milling operation as they would occur in any case. On this basis, a value of T selected without considering radon released due to U-238 in the tailings is appropriate.

With this change, the value of T given by equation 7 becomes about 115 thousand years (about 118 thousand years including a radium component), or about 1.2×10^5. To a much lesser extent, the considerations expressed above with respect to uranium also apply to thorium. However, radon releases from buried tailings over the next 100,000 years or thereabouts should be somewhat controllable. Given that some uranium ore would become uncovered by natural erosional processes over this time period, and therefore the impacts resulting from milling-related radon releases would have occurred anyway, an approximate value of 10^5 is taken as an appropriate reasonable upper limit of the value of T.

In the optimization process discussed so far, integrated costs have been compared to integrated benefits (reductions in detriment). Another equally valid and feasible approach is to compare annual costs and benefits. Annualized costs may be conceptualized as the income or revenue per year forfeited by committing a large capital investment to reclamation efforts. As indicated by the data and discussion presented in Chapter 14, this annual lost revenue on committed capital can be approximated by assuming a 1% real interest rate with the uncertainties discussed in that chapter. In terms of equation 9, annualized costs equal to 1% of the value of A_3 (again, ignoring parameter A_2 as a determinant of x and, hence, F) would replace the value of A_3, and the annualized residual detriment would be incorporated by assigning a value of unity to T. These changes would shift the analytical basis for the calculation of F_{opt} from comparison of integrated costs and benefits to comparison of annualized costs and benefits. As it turns out, this is numerically equivalent to calculating F_{opt} on the basis of integrated costs and benefits while assigning a value of 100 to the parameter T. Although real interest rates could vary upward by some degree, thus yielding a lower effective value of T, a value of 100 for T is taken to be a reasonable lower limit.

On the basis of the above discussion, the proper value of the parameter T is indeterminable but is taken to range from 100 to 100,000.

3.7 Results. A mathematical expression theoretically yielding the optimum radon flux control limit has been developed on the basis of first principles of radiation protection. This expression, although based on a simplified calculational approach, involves several dependent variables (parameters) whose proper values are clearly and largely uncertain. These parameters have been assigned values and/or ranges by available means, as summarized in Table U.1, in order to allow the calculation of the theoretical optimum radon flux control limit.

The calculated radon flux control limits are presented in Table U.2, as a function of the value assigned for the integrating factor T, for both the central values and ranges of other parameters as presented in Table U.1. Central values of the optimum flux range from 97 to 0.097 pCi/m^2-sec., for values of T ranging from 100 to 100,000 years, respectively. The full range of the optimum flux, based on the ranges of parameter values as listed in Table U.1, extends from "unlimited" to as low as 1.2×10^{-4}, which is virtually zero. The range of the optimum flux is wider yet if ultimate upper and lower bounds are considered.

Table U.1 Values and Ranges of Parameters Used in Radon Flux Optimization

Parameters and Values Used			
Parameter	Definition and Units	Central Value	Range
A_1	health effects/yr per pCi/m^2-sec of Rn released	0.021	0.0021[a] to 0.21
A_3	millions of $ per meter of earth cover applied	106.	76 to 320
A_4	radon flux attenuation coefficient, per meter	1.3	0.8 to 3.0
A_5	millions of $ per health effect	0.4[c]	0.02 to 10
T	effective number of years of annual health effects counted	–	100 to 100,000[b]

[a] An ultimate lower limit of zero is possible.

[b] An ultimate upper limit of 4.5 x 10^8 has been determined.

[c] Central values given here for other parameters result directly from staff analysis and are correctly interpreted as staff "best estimates." The central value shown for the dollar worth of a health effect merely represents a middle value in a wide range of values appearing in the open literature; it is not otherwise adopted or endorsed by the staff.

Table U.2 Results Obtained in Radon Flux Optimization

	Calculated Optimum Radon Flux Limits, pCi/m^2-sec	
Value of Parameter T, yrs	Central Value	Range[a]
450,000,000	0.000022	0.00000003 to 0.021
100,000	0.097	0.00012 to 95
10,000	0.97	0.0012 to unlimited
1,000	9.7	0.012 to unlimited
100	97.	0.12 to unlimited

[a] Values shown are those obtained by minimizing or maximizing the optimum flux with respect to all parameters except T, by using parameter ranges listed in Table U.1. The ultimate minimum value of parameter A_1 may be zero, in which case no radon flux control would be optimum, regardless of the values of other parameters.

4. SUMMARY AND CONCLUSIONS

The process of cost-benefit balancing, or more specifically, optimization, has been applied to determine the optimum control level for the residual radon flux from reclaimed uranium tailings. This procedure has not yielded definitive results because of the levels of uncertainty involved. These uncertainties are so large as to completely dominate and obscure the results of a purely quantitative analysis of the optimum radon flux control level. Additionally, those uncertainties that have been considered fail to address, in this simplified analysis, other large uncertainties introduced by acknowledgement of important unresolved institutional questions such as:

a. Should available societal resources be committed to protection from tailings-emanated radon when greater benefits might derive from other applications?

b. Should health risks occurring far in the future be valued as though they were occurring now? and if not, how should future health risks be valued?

c. Is it really worth reducing risks which, on an individual basis, are at least extremely small and may even be zero?

d. Should present generations be permitted to bequeath a legacy of continuing undeserved radiation exposure?

These questions are, quite simply, beyond technical resolution. Although pertinent and important, they so involve emotional, political, and even religious considerations that the application of purely scientific knowledge and analysis is of no avail. Perspectives on how these questions should be answered varied widely among commentors on the draft GEIS. Many stated that the tailings isolation problem should be properly viewed as a short-term one when weighing the amount of radon control that should be required; for example, 100 years was urged as the period over which health effects should be integrated. Other commentors urged that the full period of toxicity should be considered and, based on this and the large number of potential health effects, virtually no radon releases from the tailings should be allowed.

Notwithstanding the enormous subjectivity involved with these questions some might be willing to make judgments about them and select values for the parameters described in Section 2 and 3 that, for example, lie somewhere between the extremes. The optimization methodology would still break down for the case of the uranium mill tailings disposal problem, however. This is largely due to the impossibility of correlating containment performance uniquely with all applicable costs (that is, relating x to parameter A_2 as discussed in Section 3.2).

The uncertainty associated with containment performance is vastly different from other radioactive environmental control or waste management cases where incremetal cost-benefit analysis might, in some cases, be reasonably relied upon. Tailings impoundments constitute large, diffuse and essentially permanent area sources as opposed to finite-term point sources which are amenable to mechanical emission control equipment. The hazards in the tailings are very long-lived and the contaiment will need to be similarly durable. Therefore, there is very large uncertainty as to the long-term isolation performance, unlike what would be the case when controlling a stack emission for a short period of time. As opposed to being disposed of in deep geological formations, tailings are being disposed of near-surface where conditions affecting performance are much more rapidly changing with time.

Also as discussed previously, there is a strong interrelationship among the various goals of tailings management. In some cases, there is competition among objectives. For example, in attempting to provide greater containment of radon and long-term stability by placing tailings further below grade with increasingly thicker covers, tailings are being put closer to groundwater formations making groundwater protection objectives more difficult to achieve. In other cases, working to achieve one objective also contributes toward attainment of another. For example, placing cover over a tailings pile not only reduces radon emissions and the associated impacts, but also provides some isolation from intrusion and reduces potential for tailings misuse. It is not possible to monetize these interrelated factors so as to assure that the cost-benefit optimization is a realistic one.

References

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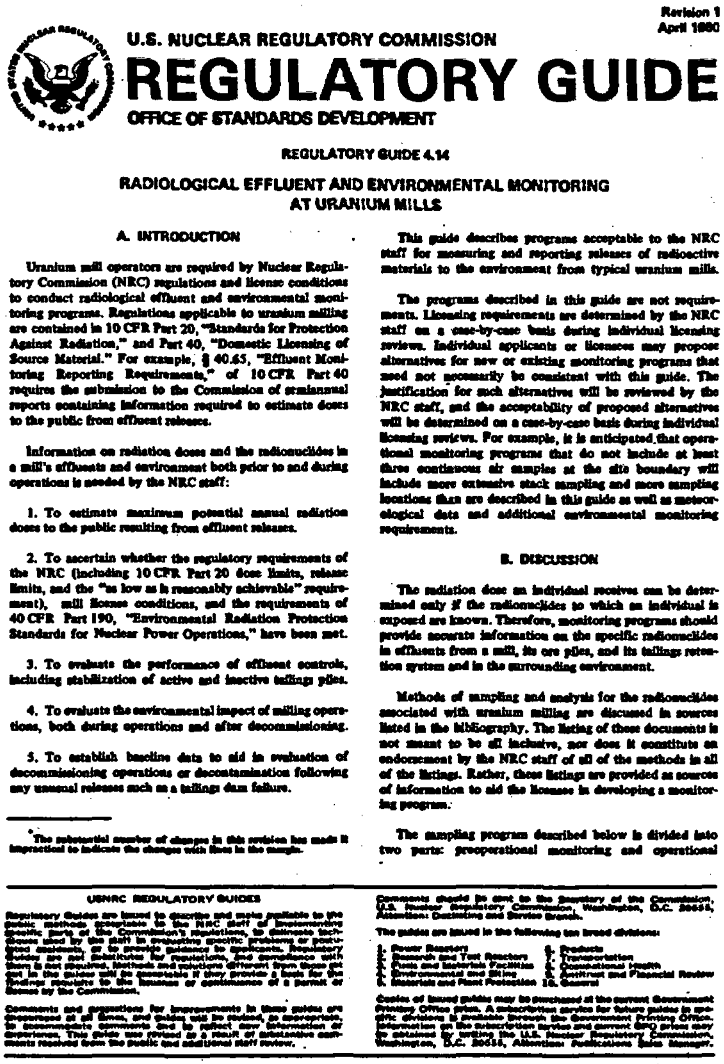
APPENDIX V. RADIOLOGICAL EFFLUENT AND ENVIRONMENTAL MONITORING AT URANIUM MILLS



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RADIOLOGICAL EFFLUENT AND ENVIRONMENTAL MONITORING AT URANIUM MILLS

A. INTRODUCTION

Uranium mill operators are required by Nuclear Regulatory Commission (NRC) regulations and license conditions to conduct radiological effluent and environmental monitoring programs. Regulations applicable to uranium milling are contained in 10 CFR Part 20, "Standards for Protection Against Radiation," and Part 40, "Domestic Licensing of Source Material." For example, § 40.65, "Effluent Monitoring Reporting Requirements," of 10 CFR Part 40 requires the submission to the Commission of semiannual reports containing information required to estimate doses to the public from effluent releases.

Information on radiation doses and the radionuclides in a mill's effluents and environment both prior to and during operations is needed by the NRC staff:

1. To estimate maximum potential annual radiation doses to the public resulting from effluent releases.

2. To ascertain whether the regulatory requirements of the NRC (including 10 CFR Part 20 dose limits, release limits, and the "as low as is reasonably achievable" requirement), mill license conditions, and the requirements of 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," have been met.

3. To evaluate the performance of effluent controls, including stabilization of active and inactive tailings piles.

4. To evaluate the environmental impact of milling operations, both during operations and after decommissioning.

5. To establish baseline data to aid in evaluation of decommissioning operations or decontamination following any unusual releases such as a tailings dam failure.

This guide describes programs acceptable to the NRC staff for measuring and reporting releases of radioactive materials to the environment from typical uranium mills.

The programs described in this guide are not requirements. Licensing requirements are determined by the NRC staff on a case-by-case basis during individual licensing reviews. Individual applicants or licensees may propose alternatives for new or existing monitoring programs that need not necessarily be consistent with this guide. The justification for such alternatives will be reviewed by the NRC staff, and the acceptability of proposed alternatives will be determined on a case-by-case basis during individual licensing reviews. For example, it is anticipated that operational monitoring programs that do not include at least three continuous air samples at the site boundary will include more extensive stack sampling and more sampling locations than are described in this guide as well as meteorological data and additional environmental monitoring requirements.

B. DISCUSSION

The radiation dose an individual receives can be determined only if the radionuclides to which an individual is exposed are known. Therefore, monitoring programs should provide accurate information on the specific radionuclides in effluents from a mill, its ore piles, and its tailings retention system and in the surrounding environment.

Methods of sampling and analysis for the radionuclides associated with uranium milling are discussed in sources listed in the bibliography. The listing of these documents is not meant to be all inclusive, nor does it constitute an endorsement by the NRC staff of all of the methods in all of the listings. Rather, these listings are provided as sources of information to aid the licensee in developing a monitoring program.

The sampling program described below is divided into two parts: preoperational monitoring and operational

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*The substantial number of changes in this revision has made it impractical to indicate the changes with lines in the margin.

monitoring. Preoperational data is submitted to the NRC as part of the application process. Operational data is reported as required by § 40.65 of 10 CFR Part 40 and specific license conditions and at times of license renewal.

C. REGULATORY POSITION

1. PREOPERATIONAL MONITORING

An acceptable preoperational monitoring program is described below and summarized in Table 1. At least twelve consecutive months of data, including complete soil sampling, direct radiation, and radon flux data, should be submitted to the NRC staff prior to any major site construction. A complete preoperational report with twelve consecutive months of data should be submitted prior to beginning milling operations. Prior to the start of local mining operations, if possible, monitoring data, including airborne radon measurements, should be submitted to the NRC staff.

Applicants may propose alternatives to this preoperational program. However, equivalent alternatives should be proposed for the operational program so that the programs remain compatible.

1.1 Preoperational Sampling Program

1.1.1 Air Samples

Air particulate samples should be collected continuously at a minimum of three locations at or near the site boundary. If there are residences or occupiable structures within 10 kilometers of the site, a continuous outdoor air sample should be collected at or near the structure with the highest predicted airborne radionuclide concentration due to milling operations and at or near at least one structure in any area where predicted doses exceed 5 percent of the standards in 40 CFR Part 190. A continuous air sample should also be collected at a remote location that represents background conditions at the mill site; in general, a suitable location would be in the least prevalent wind direction from the site and unaffected by mining or other milling operations.

Normally, filters for continuous ambient air samples are changed weekly or more often as required by dust loading.

The sampling locations should be determined according to the projected site and milling operation. Preoperational sampling locations should be the same as operational locations. The following factors should be considered in determining the sampling locations: (1) average meteorological conditions (windspeed, wind direction, atmospheric stability), (2) prevailing wind direction, (3) site boundaries nearest to mill, ore piles, and tailings piles, (4) direction of nearest occupiable structure (see footnotes of Tables 1 and 2), and (5) location of estimated maximum concentrations of radioactive materials.

Samples should be collected continuously, or for at least one week per month, for analysis of radon-222. The sampling locations should be the same as those for the continuous air particulate samples.

1.1.2 Water Samples

Samples of ground water should be collected quarterly from at least three sampling wells located hydrologically down gradient from the proposed tailings area, at least three locations near other sides of the tailings area, and one well located hydrologically up gradient from the tailings area (to serve as a background sample). The location of the ground-water sampling wells should be determined by hydrological analysis of the potential movement of seepage from the tailings area, and the basis for choosing these locations should be presented when data is reported. Wells drilled close to the tailings for the specific purpose of obtaining representative samples of ground water that may be affected by the mill tailings are preferable to existing wells.

Ground-water samples should also be collected quarterly from each well within two kilometers of the proposed tailings area that is or could be used for drinking water, watering of livestock, or crop irrigation.

Samples of surface water should be collected quarterly from each onsite water impoundment (such as a pond or lake) and any offsite water impoundment that may be subject to seepage from tailings, drainage from potentially contaminated areas, or drainage from a tailings impoundment failure.

Samples should be collected at least monthly from streams, rivers, any other surface waters or drainage systems crossing the site boundary, and any offsite surface waters that may be subject to drainage from potentially contaminated areas or from a tailings impoundment failure. Any stream beds that are dry part of the year should be sampled when water is flowing. Samples should be collected at the site boundary or at a location immediately downstream of the area of potential influence.

1.1.3 Vegetation, Food, and Fish Samples

Forage vegetation should be sampled at least three times during the grazing season in grazing areas in three different sectors having the highest predicted airborne radionuclide concentration due to milling operations.

At least three samples should be collected at time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site.

Fish (if any) samples should be collected semiannually from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.

1.1.4 Soil and Sediment Samples

Prior to initiation of mill construction (and if possible prior to mining), one set of soil samples should be collected as follows:

a. Surface-soil samples (to a depth of five centimeters) should be collected using a consistent technique at 300-meter intervals in each of the eight compass directions out to a distance of 1500 meters from the center of the milling area. The center is defined as the point midway between the proposed mill and the tailings area.

b. Surface-soil samples should also be collected at each of the locations chosen for air particulate samples.

c. Subsurface samples (to a depth of 1 meter) should be collected at the center of the milling area and at a distance of 750 meters in each of the four compass directions.

Soil sampling should be repeated for each location disturbed by site excavation, leveling, or contouring.

One set of sediment samples should be collected from the same surface-water locations as described in Section 1.1.2. For surface water passing through the site, sediment should be sampled upstream and downstream of the site. Samples should be collected following spring runoff and in late summer, preferably following an extended period of low flow. In each location, several sediment samples should be collected in a traverse across the body of water and composited for analysis.

1.1.5 Direct Radiation

Prior to initiation of mill construction (and if possible prior to mining), gamma exposure rate measurements should be made at 150-meter intervals in each of the eight compass directions out to a distance of 1500 meters from the center of the milling area. Measurements should also be made at the sites chosen for air particulate samples.

Measurements should be repeated for each location disturbed by site excavation, leveling, or contouring.

Gamma exposure measurements should be made with passive integrating devices (such as thermoluminescent dosimeters), pressurized ionization chambers, or properly calibrated portable survey instruments.

Direct radiation measurements should be made in dry weather, not during periods following rainfall or when soil is abnormally wet.

1.1.6 Radon Flux Measurements

Radon-222 flux measurements should be made in three separate months during normal weather conditions in the spring through the fall when the ground is thawed. The measurements should be made at the center of the milling area and at locations 750 and 1500 meters from the center in each of the four compass directions. Measurements should not be taken when the ground is frozen or covered with ice or snow or following periods of rain.

1.2 Analysis of Preoperational Samples

Air particulate samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

Air samples collected for radon should be analyzed for radon-222.

The results of analyses of air samples should be used to determine the radionuclide concentrations for the sampling locations.

All ground-water samples collected near the tailings area should be analyzed for dissolved natural uranium, thorium-230, radium-226, polonium-210, and lead-210. Ground-water samples from sources that could be used as drinking water for humans or livestock or crop irrigation should also be analyzed for suspended natural uranium, thorium-230, radium-226, polonium-210, and lead-210.

Surface-water samples from water impoundments should be analyzed quarterly for natural uranium, thorium-230, and radium-226 and semiannually for lead-210 and polonium-210. The samples should be analyzed separately for dissolved and suspended radionuclides.

Surface-water samples from flowing surface water should be analyzed monthly for natural uranium, thorium-230 and radium-226 and semiannually for lead-210 and polonium-210. The samples should be analyzed separately for dissolved and suspended radionuclides.

The results of analyses of water samples should be used to determine the radionuclide concentrations for the sampling locations.

Vegetation, food, and fish (edible portion) samples should be analyzed for natural uranium, thorium-230, radium-226, lead-210, and polonium-210.

All soil samples should be analyzed for radium-226. Soil samples collected at air particulate sampling locations and ten percent of all other soil samples (including at least one subsurface set) should be analyzed for natural uranium, thorium-230, and lead-210. Analysis of extra soil samples may be necessary for repeat samples collected at locations disturbed by site excavation, leveling, or contouring.

Sediment samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

2. OPERATIONAL MONITORING

An acceptable monitoring program to be conducted during construction and after the beginning of milling operations is described below and summarized in Table 2. The results of this program should be summarized quarterly and submitted to NRC semiannually pursuant to § 40.65 of 10 CFR Part 40. An acceptable reporting format is shown in Table 3.

2.1 Operational Sampling Program

2.1.1 Stack Sampling

Effluents from the yellowcake dryer and packaging stack should be sampled at least quarterly during normal operations. The sampling should be isokinetic, representative, and adequate for determination of the release rates and concentrations of uranium. The sampling should also be adequate for the determination of release rates and concentrations of thorium-230, radium-226, and lead-210 if this data cannot be obtained from other sources.

Other stacks should be sampled at least semiannually. The samples should be representative (not necessarily isokinetic) and adequate for the determination of the release rates and concentrations of uranium, thorium-230, radium-226, and lead-210.

All stack flow rates should be measured at the time of sampling.

2.1.2 Air Sampling

Air particulate samples should be collected continuously at (1) a minimum of three locations at or near the site boundary, (2) the residence or occupiable structure within 10 kilometers of the site with the highest predicted airborne radionuclide concentration, (3) at least one residence or occupiable structure where predicted doses exceed 5 percent of the standards in 40 CFR Part 190, and (4) a remote location representing background conditions. The sampling locations should be the same as those for the preoperational air samples (see Section 1.1.1). The sampling should be adequate for the determination of natural uranium, thorium-230, radium-226, and lead-210.

Normally, filters for continuous ambient air samples are changed weekly or more often as required by dust loading.

Samples should be collected continuously at the same locations, or for at least one week per month, for analysis of radon-222.

2.1.3 Water Samples

Samples of ground water should be collected from at least three sampling wells located hydrologically down gradient from the tailings area and from one background well located hydrologically up gradient. The samples should be collected monthly through the first year of operation and quarterly thereafter from the same downslope and background wells that were used for preoperational samples (see Section 1.1.2).

Samples should be collected at least quarterly from each well within two kilometers of the tailings area that is or could be used for drinking water, watering of livestock, or crop irrigation.

Samples should be collected at least quarterly from each onsite water impoundment (such as a pond or lake) and any offsite water impoundment that may be subject to seepage from tailings, drainage from potentially contaminated areas, or drainage from a tailings impoundment failure.

Samples should be collected at least monthly from any surface water crossing the site boundary and offsite streams or rivers that may be subject to drainage from potentially contaminated areas or from a tailings impoundment failure. Stream beds that are dry part of the year should be sampled when water is flowing. Operational samples should be collected upstream and downstream of the area of potential influence.

Any unusual releases (such as surface seepage) that are not part of normal operations should be sampled.

2.1.4 Vegetation, Food, and Fish Samples

Where a significant pathway to man is identified in individual licensing cases, vegetation, food, and fish samples should be collected as described below.

Forage vegetation should be sampled at least three times during the grazing season in grazing areas in three different sectors having the highest predicted airborne radionuclide concentration due to milling operations.

At least three samples should be collected at the time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site.

Fish (if any) samples should be collected semiannually from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.

2.1.5 Soil and Sediment Samples

Surface-soil samples should be collected annually using a consistent technique at each of the locations chosen for air particulate samples as described in Section 2.1.2.

Sediment samples should be collected annually from the surface-water locations described in Section 2.1.3.

2.1.6 Direct Radiation

Gamma exposure rates should be measured quarterly at the sites chosen for air particulate samples as described in Section 2.1.2. Passive integrating devices (such as thermoluminescent dosimeters), pressurized ionization chambers, or properly calibrated portable survey instruments should be used (see Regulatory Guide 4.13).

2.2 Analysis of Operational Samples

Samples from the yellowcake dryer and packaging stack should be analyzed for natural uranium. Samples should also be analyzed for thorium-230, radium-226, and lead-210 if this data cannot be obtained from other sources such as isotopic analysis of yellowcake product. Samples from other stacks should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

Air particulate samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

Air samples collected for radon should be analyzed for radon-222.

The results of analyses of air samples should be used to determine the radionuclide release rates for the stacks and the radionuclide concentrations for the stacks and other sampling locations.

Water samples should be analyzed for natural uranium, thorium-230, radium-226, polonium-210, and lead-210.

Ground-water samples from sources not expected to be used as drinking water should be analyzed for dissolved radionuclides. Ground-water samples from sources that could be used as drinking water for humans or livestock and all surface-water samples should be analyzed separately for dissolved and suspended radionuclides. These results should be used to determine radionuclide concentrations for ground water and natural bodies of water.

All vegetation, food, and fish (edible portion) samples should be analyzed for radium-226 and lead-210.

All soil samples should be analyzed for natural uranium, radium-226, and lead-210.

All sediment samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

3. QUALITY OF SAMPLES

Provisions should be made to ensure that representative samples are obtained by use of proper sampling equipment, proper locations of sampling points, and proper sampling procedures (see bibliography).

Air samples may be composited for analysis if (1) they are collected at the same location and (2) they represent a sampling period of one calendar quarter or less. Air samples should not be composited if (1) they represent a sampling period of more than one calendar quarter, (2) they are from different sampling locations, or (3) the samples are to be analyzed for radon-222.

Samples collected for analysis of radon-222 should be analyzed quickly enough to minimize decay losses.

Samples other than air samples should not be composited.

4. SOLUBILITY OF AIRBORNE RADIOACTIVE MATERIAL

Table II of Appendix B, "Concentrations in Air and Water Above Natural Background," to 10 CFR Part 20 lists separate values for soluble and insoluble radioactive materials in effluents. In making comparisons between airborne effluent concentrations and the values given in Table II of Appendix B to 10 CFR Part 20, the maximum permissible concentrations for insoluble materials should be used.

5. LOWER LIMIT OF DETECTION

The lower limits of detection for stack effluent samples should be 10% of the appropriate concentration limits listed in Table II of Appendix B to 10 CFR Part 20.

The lower limits of detection for analysis of other samples should be as follows:

U-natural, Th-230, Ra-226 in air	-	1×10^{-16} µCi/ml
Pb-210 in air	-	2×10^{-15} µCi/ml
Rn-222	-	2×10^{-10} µCi/ml
U-natural, Th-230, Ra-226 in water	-	2×10^{-10} µCi/ml
Po-210 in water	-	1×10^{-9} µCi/ml
Pb-210 in water	-	1×10^{-9} µCi/ml
U-natural, Th-230, Ra-226, Pb-210 in soil and sediment (dry)	-	2×10^{-7} µCi/g
U-natural, Th-230 in vegetation, food, and fish (wet)	-	2×10^{-7} µCi/kg
Ra-226 in vegetation, food, and fish (wet)	-	5×10^{-8} µCi/kg
Po-210, Pb-210 in vegetation, food, and fish (wet)	-	1×10^{-6} µCi/kg

Obviously, if the actual concentrations of radionuclides being sampled are higher than the lower limits of detection indicated above, the sampling and analysis procedures need only be adequate to measure the actual concentrations. In such cases, the standard deviation estimated for random error of the analysis should be no greater than 10% of the measured value.

An acceptable method for calculating lower limits of detection is described in the appendix to this guide.

6. PRECISION AND ACCURACY OF RESULTS

6.1 Error Estimates

The random error associated with the analysis of samples should always be calculated. The calculation should take into account all significant random uncertainties, not merely counting error.

If the analyst estimates that systematic errors associated with the analysis are significant relative to the random error, the magnitude of the systematic error should be estimated.

6.2 Calibration

Individual written procedures should be prepared and used for specific methods of calibrating all sampling and measuring equipment, including ancillary equipment. The procedures should ensure that the equipment will operate with adequate accuracy and stability over the range of its intended use. Calibration procedures may be compilations of published standard practices, manufacturers' instructions that accompany purchased equipment, or procedures written in-house. Calibration procedures should identify the specific equipment or group of instruments to which the procedures apply.

To the extent possible, calibration of measuring equipment should be performed using radionuclide standards certified by the National Bureau of Standards or standards obtained from suppliers who participate in measurement assurance activities with the National Bureau of Standards (see Regulatory Guide 4.15).

Calibrations should be performed at regular intervals, at least semiannually, or at the manufacturer's suggested interval, whichever is more frequent. Frequency of calibration should be based on the stability of the system. If appropriate, equipment may be calibrated before and after use instead of at arbitrarily scheduled intervals. Equipment should be recalibrated or replaced after any repairs or whenever it is suspected of being out of adjustment, excessively worn, or otherwise damaged and not operating properly. Functional tests, i.e., routine checks performed to demonstrate that a given instrument is in working condition, may be performed using sources that are not certified by the National Bureau of Standards.

6.3 Quality of Results

A continuous program should be prepared and implemented for ensuring the quality of results and for keeping random and systematic uncertainties to a minimum. The procedures should ensure that samples and measurements are obtained in a uniform manner and that samples are not changed prior to analysis because of handling or because of their storage environment. Tests should be applied to analytical processes, including duplicate analysis of selected effluent samples and periodic cross-check analyses with independent laboratories (see Regulatory Guide 4.15).

7. RECORDING AND REPORTING RESULTS

This section provides guidelines for recording all results. Reports submitted to NRC should be prepared using these guidelines and the format shown in Table 3 of this guide.

7.1 Sampling and Analysis Results

7.1.1 Air and Stack Samples

For each air or stack sample, the following should be recorded:

1. Location of sample.
2. Dates during which sample was collected.
3. The concentrations of natural uranium, thorium-230, radium-226, lead-210, and radon-222 for all samples except stack samples.
4. The cconcentration of natural uranium, thorium-230, radium-226, and lead-210 for stack effluent samples.
5. The percentage of the appropriate concentration limit as shown in Table II of Appendix B to 10 CFR Part 20.
6. The estimated release rate of natural uranium, thorium-230, radium-226, and lead-210 for stack effluent samples.
7. The flow rate of each stack.

7.1.2 Liquid Samples

For each liquid sample, the following should be recorded:

1. Location of sample.
2. Type of sample (ground or surface water).
3. Date of sample collection.
4. The concentrations of natural uranium, thorium-230, radium-226, polonium-210, and lead-210. (If separate analyses were conducted for dissolved and suspended radionuclides, report each result separately.)

7.1.3 Other Samples

For other samples, the following should be recorded:

1. Location of sample.
2. Date of sample collection.
3. Type of sample (vegetation, soil, radon-222 flux, gamma exposure rate, etc.).
4. Analytical result (radionuclide concentration, gamma exposure rate, radon flux rate, etc.).

7.1.4 Error Estimates

Reported results should always include estimates of uncertainty. The magnitude of the random error of the analysis to the 95% uncertainty level should be reported for each result. If significant, an estimate of the magnitude of the systematic error should also be reported.

7.2 Supplemental Information

The following information should be included in each monitoring report submitted to NRC:

1. Name of facility, location, docket number, and license number.
2. Description of sampling equipment and discussion of how sampling locations were chosen.

3. Description of sampling procedures, including sampling times, rates, and volumes.
4. Description of analytical procedures.
5. Description of calculational methods.
6. Discussion of random and systematic error estimates, including methods of calculation and sources of systematic error.
7. The values of the lower limits of detection, along with a description of the calculation of the lower limit of detection.
8. The values of maximum permissible concentration from Table II of Appendix B to 10 CFR Part 20 used in any calculations.
9. Discussion of the program for ensuring the quality of results.
10. Description of calibration procedures.
11. Discussion of any unusual releases, including the circumstances of the release and any data available on the quantities of radionuclides released.

7.3 Units

Radionuclide quantities should be reported in curies. Radionuclide concentrations should be reported in microcuries per milliliter for air and water, microcuries per gram for soil and sediment, and microcuries per kilogram for vegetation, food, or fish. Direct radiation exposure rates should be reported in milliroentgens per calendar quarter. Radon flux rates should be reported in picocuries per square meter per second. Stack flow rates should be reported in cubic meters per second. (In the International System of Units, a curie equals 3.7×10^{10} becquerels, a microcurie equals 3.7×10^{4} becquerels, and a milliliter equals 10^{-6} cubic meters.)

Estimates of random error should be reported in the same units as the result itself. Estimates of systematic error should be reported as a percentage of the result.

Note: The Commission has discontinued the use in 10 CFR Part 20 of the special curie definitions for natural uranium and natural thorium (39 FR 23990, June 28, 1974). Reports to the Commission should use units consistent with this change.

7.4 Significant Figures

Results should not be reported with excessive significant figures, so that they appear more certain than they actually are. The reported estimate of error should contain no more than two significant figures. The reported result itself should have the same number of decimal places as the reported error.

7.5 Format

Reports should be submitted according to the format shown in Table 3.

The term "not detected," "less than the lower limit of detection (LLD)," or similar terms should never be used. Each reported result should be a value and its associated error estimate, including values less than the lower limit of detection or less than zero.

TABLE 1

PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
AIR						
Particulates	Three	At or near the site boundaries	Continuous[a]	Weekly filter change or more frequently as required by dust loading	Quarterly composites of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
	One	At or close to the nearest[b] residence(s) or occupiable offsite structure(s) (if within 10 km of site)	Continuous	Weekly filter change or more frequently as required by dust loading	Quarterly composites of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
	One	At a control or background location remote from site[c]	Continuous	Weekly filter change or more frequently as required by dust loading	Quarterly composites of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
Radon Gas[d]	Five or more	Same locations as for air particulates	Continuous or at least one week per month representing about the same period each month	Continuous	Each sample or continuous	Rn-222
WATER						
Ground Water[e]	Six or more	Wells located around future tailings disposal area. At least three wells hydrologically down gradient from disposal area. At least three located on other sides of tailings disposal area.[f]	Grab	Quarterly	Quarterly	Dissolved natural uranium, Ra-226, Th-230, Pb-210, and Po-210
	One from each well	Wells within 2 km of tailings disposal area that are or could be used for potable water supplies, watering of livestock, or crop irrigation.	Grab	Quarterly	Quarterly	Dissolved and suspended natural uranium, Ra-226, Th-230, Pb-210, and Po-210
	One	Well located hydrologically up gradient from tailings disposal area to serve as control or background location.	Grab	Quarterly	Quarterly	Dissolved natural uranium, Ra-226, Th-230, Pb-210, and Po-210

TABLE 1 (Continued)

PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Surface Water[g]	One from each body of water	Large permanent onsite water impoundments or offsite impoundments that may be subject to direct surface drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.	Grab	Quarterly	Quarterly	Suspended and dissolved natural uranium, Ra-226 and Th-230
					Semiannually	Suspended and dissolved Pb-210 and Po-210
Surface Water	One from each body of water	Surface waters passing through the site[e] or offsite surface waters that may be subject to drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.	Grab	Monthly	Monthly	Suspended and dissolved natural uranium, Ra-226, Th-230
					Semiannually	Suspended and dissolved Pb-210 and Po-210
VEGETATION, FOOD, AND FISH						
Vegetation	Three	Grazing areas near the site in different sectors that will have the highest predicted air particulate concentrations during milling operations.	Grab	Three times during grazing season	Three times	Natural uranium, Ra-226, Th-230, Pb-210, and Po-210
Food	Three of each type	Crops, livestock, etc. raised within 3 km of mill site	Grab	Time of harvest or slaughter	Once	Natural uranium, Ra-226, Th-230, Pb-210, and Po-210
Fish	Each body of water	Collection of fish (if any) from lakes, rivers, and streams in the site environs that may be subject to seepage or direct surface runoff from potentially contaminated areas or that could be affected by a tailings impoundment failure	Grab	Semiannually	Twice	Natural uranium, Ra-226, Th-230, Pb-210, and Po-210

TABLE 1 (Continued)

PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
SOIL AND SEDIMENT						
Surface Soil(k)	Up to forty	300-meter intervals to a distance of 1500 meters in each of 8 directions from center of milling area	Grab	Once prior to site construction. Repeat for location disturbed by excavation, leveling, or contouring	Once	All samples for Ra-226, 10% of samples natural uranium, Th-230, and Pb-210
Surface Soil	Five or more	At same locations used for collection of air particulate samples.	Grab	Once prior to site construction	Once	Natural uranium, Ra-226, Th-230, and Pb-210
Subsurface Soil Profile(l)	Five	At center reference location and at distances of 750 meters in each of 4 directions.	Grab	Once prior to site construction. Repeat for locations disturbed by construction.	Once	Ra-226 (all samples) Natural uranium, Th-230, and Pb-210 (one set of samples)
Sediment(m)	Two from each stream	Up and downstream of surface waters passing through site or from offsite surface waters that may be subject to direct runoff from potentially contaminated areas or that could be affected by a tailings impoundment failure	Grab	Once following spring runoff and late summer following period of extended low flow	Twice	Natural uranium, Ra-226, Th-230, and Pb-210
	One from each water impoundment	Onsite water impoundments (lakes, ponds, etc), or offsite impoundments that may be subject to direct surface runoff from potentially contaminated areas or that could be affected by tailings impoundment failure	Grab	Once prior to site construction	Once	Natural uranium, Ra-226, Th-230, and Pb-210
DIRECT RADIATION	Up to eighty	150-meter intervals to a distance of 1500 meters in each of 8 directions from center of milling area or at a point equidistant from milling area(l) and tailings disposal area.		Once prior to site construction. Repeat for areas disturbed by site preparation or construction.	Once	Gamma exposure rate, using passive integrating device such as TLD, pressurized ionization chamber, or properly calibrated portable survey instrument.

TABLE 1 (Continued)

PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	Five or more	At same locations used for collection of particulate samples		Once prior to site construction	Once	Gamma exposure rate, using passive integrating device, pressurized ionization chamber, or properly calibrated portable survey instrument.
RADON FLUX(m)	Up to ten	At center reference location and at distances of 750 and 1500 meters in each of 4 directions.		One sample during each of three months.	Each sample	Radon-222 flux

TABLE 2

OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
STACKS						
Particulates	One for each stack	Yellowcake dryer and packaging stack(s)	Isokinetic	Quarterly	Each sample	Natural uranium, Th-230, Ra-226, and Pb-210 if not available from other sources. Measure stack flow rate semiannually.
Particulates	One for each stack	Other stacks	Representative grab	Semiannually	Each sample	Natural uranium Th-230, Ra-226, and Pb-210. Measure stack flow.
AIR						
Particulates	Three	Locations at or near the site boundaries and in different sectors that have the highest predicted concentrations of airborne particulates(b)	Continuous(a)	Weekly filter change, or more frequently as required by dust loading	Quarterly composite, by location, of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
	One or more	At the nearest residence(s) or occupiable structure(s)	Continuous	Weekly filter change, or more frequently as required by dust loading	Quarterly composite, by location, of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
	One	Control Location(s)(c)	Continuous	Weekly filter change, or more frequently as required by dust loading	Quarterly composite, by location, of weekly samples	Natural uranium, Ra-226, Th-230, and Pb-210
Radon Gas	Five or more	Same locations as for air particulates	Continuous or at least one week per month(d)	At least one week per calendar month representing approximately the same period each month	Monthly	Rn-222
WATER						
Ground Water	Three or more	Hydrologically down gradient and relatively close to the tailings impoundment(f)	Grab	Monthly (first year) Quarterly (after first year)	Monthly (first year) Quarterly (after first year)	Dissolved natural uranium, Ra-226, Th-230, Pb-210, and Po-210(e)
	At least one control sample	Hydrologically up gradient (i.e., not influenced by seepage from tailings)	Grab	Quarterly	Quarterly	Dissolved natural uranium, Ra-226, Th-230, Pb-210 and Po-210

TABLE 2 (Continued)

OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	*Sample Collection*				*Sample Analysis*	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	One from each well	Each well used for drinking water or watering of livestock or crops within 2 km of the tailings impoundment	Grab	Quarterly	Quarterly	Dissolved and suspended natural uranium, Ra-226, Th-230, Pb-210, and Po-210
Surface Water	Two from each water body	Surface waters passing through the mill site or offsite surface waters that are sufficiently close to the site to be subject to surface drainage from potentially contaminated areas or that could be influenced by seepage from the tailings disposal area.(h) One sample collected upstream of mill site and one sample collected at the downstream site boundary or at a location immediately downstream of location of potential influence	Grab	Quarterly	Quarterly	Dissolved and suspended natural uranium, Ra-226, Th-230, Pb-210, and Po-210(g)
	One from each water body	Large water impoundments (i.e., lakes, reservoirs) near the mill site that are sufficiently close to the site to be subject to drainage from potentially contaminated areas or that could be influenced by seepage from the tailings disposal area.	Grab	Quarterly	Quarterly	Dissolved and suspended natural uranium, Ra-226, Th-230, Pb-210, and Po-210
VEGETATION, FOOD, AND FISH						
Vegetation or Forage(e)	Three or more	From animal grazing areas near the mill site in the direction of the highest predicted airborne radionuclide concentrations	Grab	Three times during grazing season	Each sample	Ra-226 and Pb-210

TABLE 2 (Continued)

OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR URANIUM MILLS

Type of Sample	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Food	Three of each type	Crops, livestock, etc. raised within 3 km of mill site	Grab	Time of harvest or slaughter	Once	Ra-226 and Pb-210
Fish	Each body of water	Collection of fish (if any) from lakes, rivers, and streams in the site environs that may be subject to seepage or direct surface runoff from potentially contaminated areas or that could be affected by a tailings impoundment failure	Grab	Semiannually	Twice	Ra-226 and Pb-210
SOIL AND SEDIMENT						
Soil	Five or more	Same as for air particulate samples(k)	Grab	Annually	Annually	Natural uranium, Ra-226, and Pb-210
Sediment	One or two from each water body	Same as surface water samples(m)	Grab	Annually	Annually	Natural uranium, Th-230, Ra-226, and Pb-210
DIRECT RADIATION	Five or more	Same as for air particulate samples	Continuous passive integrating device	Quarterly change of passive dosimeters	Quarterly	Gamma exposure rate

Footnotes for Tables 1 and 2:

(a) Continuous collection means continuous sampler operation with filter change weekly or as required by dust loading, whichever is more frequent.

(b) The term "nearest" as used here means the location with the highest predicted airborne radionuclide concentrations during milling operations.

(c) Care should be taken in selection of the control sampling location so that it is representative of the site conditions. In general, a location in the least prevalent wind direction from the site should provide a suitable location for a control sampling site.

(d) Various methods are acceptable; for example: (1) Continuous collection of a gaseous air sample with samples being changed about every 48 hours for a 1-week period or (2) continuous sampling.

(e) If the sample contains appreciable suspended material, it should be filtered as soon as possible following collection through a membrane filter and the filtrate acidified to 1% hydrochloric acid.

(f) The location of the ground-water sampling wells should be determined by a hydrological analysis of the potential movement of seepage from the tailings disposal area. In general, the objective is to place monitor wells in all directions around the tailings area with the emphasis on the down gradient locations.

(g) Surface-water samples to be analyzed for dissolved and suspended fractions should be filtered as soon as possible following collection through a membrane filter and the filtrate acidified to 1% hydrochloric acid.

(h) Natural drainage systems (dry washes) that carry surface runoff from the site following a precipitation event should be sampled following the event but at a frequency not greater than monthly.

(i) The milling area refers to the area that includes ore storage pads, mill buildings, and other processing areas.

(j) Thermoluminescent dosimeters should contain two or more chips or otherwise provide for two readings per exposure period (see Regulatory Guide 4.13).

(k) Surface soil samples should be collected using a consistent technique to a depth of 5 cm.

(l) Subsurface soil profile samples should be collected to a depth of one meter. Samples should be divided into three equal sections for analysis.

(m) Several samples should be collected at each location and composited for a representative sample.

(n) Radon exhalation measurements should not be taken during periods when the ground is frozen or covered with ice or snow or following periods of rain. It is recommended that these measurements be taken in the spring through the fall during normal weather conditions.

(o) Vegetation or forage sampling need be carried out only if dose calculations indicate that the ingestion pathway from grazing animals is a potentially significant exposure pathway (an exposure pathway should be considered important if the predicted dose to an individual would exceed 5% of the applicable radiation protection standard).

TABLE 3(a)

SAMPLE FORMAT FOR REPORTING MONITORING DATA

1. STACK SAMPLES

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Stack flow rate (m^3/sec)

Radionuclide	Concentration (µCi/ml)	Error Estimate(b) (µCi/ml)	Release Rate (Ci/yr)	Error Estimate (Ci/yr)	LLD(c) (µCi/ml)	% MPC(c)
U-nat						
Th-230						
Ra-226						
Pb-210						

2. AIR SAMPLES

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection

Radionuclide	Concentration (µCi/ml)	Error Estimate (µCi/ml)	LLD (µCi/ml)	% MPC
U-nat				
Th-230				
Ra-226				
Pb-210				
Rn-222				

(a) This table illustrates format only. It is not a complete list of data to be reported. (See text of guide and Tables 1 and 2.)

(b) Error estimate should be calculated at 95% uncertainty level, based on all sources of random error, not merely counting error. Significant systematic error should be reported separately. See Sections 6.1, 7.1.4, and 7.3.

(c) All calculations of lower limits of detection (LLD) and percentages of maximum permissible concentration (MPC) should be included as supplemental information.

TABLE 3 (Continued)

SAMPLE FORMAT FOR REPORTING MONITORING DATA

3. LIQUID SAMPLES

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample (for example: surface, ground, drinking, stock, or irrigation)

Radionuclide	Concentration (µCi/ml)	Error Estimate (µCi/ml)	LLD (µCi/ml)
U-nat (dissolved)			
U-nat (suspended)(d)			
Th-230 (dissolved)			
Th-230 (suspended)(d)			
Ra-226 (dissolved)			
Ra-226 (suspended)(d)			
Pb-210 (dissolved)			
Pb-210 (suspended)(d)			
Po-210 (dissolved)			
Po-210 (suspended)(d)			

4. VEGETATION, FOOD, AND FISH SAMPLES

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample and portion analyzed

Radionuclide	Concentration (µCi/kg wet)	Error Estimate (µCi/kg)	LLD (µCi/kg)
U-nat			
Th-230			
Ra-226			
Pb-210			
Po-210			

(d) Not all samples must be analyzed for suspended radionuclides. See Sections 1.2 and 2.2 of this guide.

TABLE 3 (Continued)

SAMPLE FORMAT FOR REPORTING MONITORING DATA

5. SOIL AND SEDIMENT SAMPLES

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample and portion analyzed

Radionuclide	Concentration (µCi/g)	Error Estimate (µCi/g)	LLD (µCi/g)
U-nat			
Th-230			
Ra-226			
Pb-210			
Po-210			

6. DIRECT RADIATION MEASUREMENTS

For each measurement, report the dates covered by the measurement and the following information:

Location	Exposure Rate (mR/qr)	Error Estimate (mR/qr)

7. RADON FLUX MEASUREMENTS

For each measurement, report the dates covered by the measurement and the following information:

Location	Flux (pCi/m^2-sec)	Error Estimate (pCi/m^2-sec)

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APPENDIX

LOWER LIMIT OF DETECTION

For the purposes of this guide, the Lower Limit of Detection (LLD) is defined as the smallest concentration of radioactive material sampled that has a 95% probability of being detected, with only a 5% probability that a blank sample will yield a response interpreted to mean that radioactive material is present. (Radioactive material is "detected" if it yields an instrument response that leads the analyst to conclude that activity above the system background is present.)

For a particular measurement system (which may include radiochemical separation):

$$\text{LLD} = \frac{4.66\ S_b}{3.7 \times 10^4\ EVY \exp(-\lambda \Delta t)}$$

where

LLD	is the lower limit of detection (microcuries per milliliter);
S_b	is the standard deviation of the instrument background counting rate (counts per second);
3.7×10^4	is the number of disintegrations per second per microcurie;
E	is the counting efficiency (counts per disintegration);
V	is the sample volume (milliliters);
Y	is the fractional radiochemical yield (when applicable);
λ	is the radioactive decay constant for the particular radionuclide; and
Δt	is the elapsed time between sample collection and counting.

The value of S_b used in the calculation of the LLD for a particular measurement system should be based on the actual observed variance of the instrument background counting rate rather than an unverified theoretically predicted variance.

Since the LLD is a function of sample volume, counting efficiency, radiochemical yield, etc., it may vary for different sampling and analysis procedures. Whenever there is a significant change in the parameters of the measurement system, the LLD should be recalculated.*

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*For a more complete discussion of the LLD, see "HASL Procedures Manual," John H. Harley, editor, USERDA, HASL-300 (revised annually) and Currie, L.A., "Limits for Qualitative Detection and Quantitative Determination—Application to Radiochemistry," *Anal. Chem.* 40, 1968, pp. 586-93, and Donn, J. J. and R. L. Wolke, "The Statistical Interpretation of Counting Data from Measurements of Low-Level Radioactivity," *Health Physics*, Vol. 32, 1977, pp. 1-14.

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The Final Generic Environmental Impact Statement (GEIS) on Uranium Milling focuses primarily upon the matter of mill tailings disposal. It evaluates both the costs and benefits of alternative tailings disposal modes and draws conclusions about criteria which should be incorporated into regulations. Both institutional and technical controls are evaluated. Health impacts considered were both short and long term. Restatement and resolution of all public comments received on the draft (GEIS) are presented. There are three volumes: Volume I is the main text and Volumes II and III are supporting appendices.

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