Environmental Control Technology for Mining, Milling, and Refining Thorium

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February 1980

Prepared for the
Environmental Control Technology Division
U.S. Department of Energy
under Contract DE-AC06-76RLO-1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$ _____ *: Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

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SUMMARY AND RECOMMENDATIONS

In order to meet the increased demands for reactor-grade thorium (ThO_2) that a conversion to the thorium fuel cycle would require, new domestic deposits will have to be mined. This study examined the type and level of wastes that would be generated in the mining, milling, and refining of ThO_2 from seven potential domestic sources of thorium. The estimated costs of the technology to control these wastes to different degrees of stringency are presented.

The incremental cost of ThO_2 production for waste control could vary not only with the level of control but from site to site (see Figure 1). The maximum incremental cost of environmental control technology per pound of thorium ranges from \$13.55 at the Lemhi Pass deposit to \$0.71 at the Palmer, Michigan, deposit. The major differences between the costs at these two sites are caused by the amount of ore processed and the treatment process for the tailings from the mills and refineries. At Palmer, Michigan, more thorium would be produced and the tailings would be buried onsite by simple methods while at Lemhi Pass less thorium but more highly radioactive tailings would be produced; these tailings would be blended with asphalt and trucked to an onsite burial ground for disposal. These differences, as well as many others among the other sites, cause the environmental control technology costs to be highly site- and process-specific.

The major wastes generated at most sites would be similar in type (dust, water, etc.), but the radioactive content would vary, depending on the ore grade. The major cost would be for controlling the waste water and tailings from the mines, mills, and refineries. The type of control method that would be used depends on the water volume and its radioactivity level. Waste water control consists of tailings ponds, pond covers, beach dust spraying, and, in some cases, dewatering and material additions to immobilize the radioactive constituents.

FIGURE 1. Domestic Thorium Oxide Costs

This study indicated that most of the environmental control technology costs (up to about 90%) at each site would be for the control of mill and refinery tailings. The unit costs were generally much lower in cases where the throughput rates and ore grades were higher. It could cost over an order of magnitude more to reduce the amount of a specific effluent released by the last 1 or 2%.

The technologies used in this study have the potential to effectively hold the discharge of effluents to very low levels. Many of the environmental control methods used in the uranium industry should also be applicable for use in the thorium industry. It should be easier to control the offsite effluents for thorium than for uranium because the migration of thoron (radon) and its daughters is easier to prevent, due to their shorter half-lives. These shorter half-lives also reduce the radioactivity of the tailings piles substantially within 50 years.

There is a lack of recent data dealing with industrial-scale thorium oxide production. Most of the process and production data in the literature are over two decades old with little data on the release and control of effluents. If there were a transition to a thorium fuel cycle, we recommend research to:

- obtain site-specific data from the deposit to be developed (e.g. ore analysis, hydrology, ecology, etc.),
- define flow sheet and processes for the specific sites,
- analyze the radon concentrations and retention parameters likely to be encountered in mines and tailings piles.

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1.0 INTRODUCTION

In recent years, political opinion has prompted the reassessment of the thorium fuel cycle for nuclear power production as a deterrent to the proliferation of nuclear weapons. In a nuclear reactor, thorium breeds the fertile isotope, ^{233}U , rather than plutonium, which is bred in uranium fueled reactors. Either plutonium or uranium-233, depending on the fuel cycle, can be separated from the irradiated fuel and mixed with natural or depleted uranium ^{238}U to form new fuel. Conceivably, this nuclear fuel material could be diverted by terrorists or foreign governments and utilized for weapons manufacture. Unlike plutonium, however, the fissile isotope ^{233}U can only be separated from the depleted uranium by an expensive isotopic separations process. Thus, the thorium fuel cycle is attractive from a safeguards viewpoint.

If the thorium fuel cycle was adopted for nuclear power production, new thorium supply sources would have to be developed. The availability of the thorium, its cost of production, and the capability and the cost of controlling wastes from its production would be of major importance in a policy decision to implement thorium fuel cycle reactors.

The purpose of this report is to evaluate, in terms of cost and effectiveness, the various environmental control technologies that would be used to control the radioactive wastes generated in the mining, milling, and refining of thorium from domestic resources. The technologies, in order to be considered for study, had to reduce the radioactivity in the waste streams to meet Atomic Energy Commission (10 CFR 20) standards for natural thorium's maximum permissible concentration (MPC) in air and water. Further regulatory standards or licensing requirements, either federal, state, or local, were not examined. The availability and cost of producing thorium from domestic resources is addressed in a companion volume.⁽¹⁾

The objectives of this study were 1) to identify the major waste streams generated during the mining, milling, and refining of reactor-grade thorium oxide from domestic resources, and 2) to determine the cost and levels of control of existing and advanced environmental control technologies for these waste streams.

Six potential domestic deposits of thorium oxide, in addition to stock-piled thorium sludges, are discussed in this report. A seventh deposit at Bear Lodge, Wyoming, has been identified recently but no process data is available for this ore. Due to the lack of data and time constraints, the Bear Lodge deposit is not included in this study. A summary of the location and characteristics of the potential domestic thorium resources and the mining, milling, and refining processes that will be needed to produce reactor-grade thorium oxide is presented in Section 2. The wastes from existing and potential domestic thorium oxide mines, mills, and refineries are identified in Section 3. Section 3 also presents the state-of-the-art technology and the costs associated with controlling the wastes from the mines, mills, and refineries. In Section 4, the available environmental control technologies for mines, mills, and refineries are assessed. Section 5 presents the cost and effectiveness estimates for the various environmental control technologies applicable to the mine, mill, and refinery for each domestic resource.

REFERENCES

1. Young, J.K. et al. February 1980. Economics of Large-Scale Thorium Oxide Production: Assessment of Domestic Resources, PNL-3150, Pacific Northwest Laboratory, Richland, Washington 99352.

2.0 DOMESTIC THORIUM RESOURCES

Thorium mineralization consists primarily of thorite (Th SiO_4), monazite, and, to a lesser degree, pyrochlore. The locations of the deposits discussed in this study are shown in Figure 2.1. Deposit characteristics and the processing techniques utilized to develop the various thorium resources are discussed in the following sections.

2.1 LOCATION AND CHARACTERISTICS

2.1.1 Stockpiles

The primary industrial stockpile for thorium is owned by W. R. Grace and Company in Chattanooga, Tennessee. Thorium sludge is currently obtained as a byproduct of monazite sand processing for rare earths and stockpiled at a rate of 250 ton/yr. An estimated backlog of 1500 tons of ThO_2 equivalent is contained in the ponds. The thorium sludge is reported to contain 25% ThO_2 and some uranium (assumed to be ~1%).

Government stockpiles exist at Curtis Bay, Maryland; Miamisburg, Ohio; and Fernald, Ohio. These stockpiles are primarily in the form of thorium nitrates. Approximately 800 tons of ThO_2 equivalent are stored at Curtis Bay, Maryland, and another 400 tons of ThO_2 equivalent are located in Miamisburg, Ohio. These stockpiles are assayed at approximately 46% ThO_2 . Another 360 metric tons of ThO_2 equivalent assayed at 88% ThO_2 are stored in Fernald, Ohio.

2.1.2 Lemhi Pass Deposit

The thorium-bearing vein deposits in the Lemhi Pass area have been described in the literature by Staatz.^(1,2) The Lemhi Pass quadrangle, lying astride the Continental Divide, occupies approximately 53 sq. miles in the east-central part of the Beaverhead Mountains of Idaho and Montana. Although the Lemhi Pass thorium district is much larger, the quadrangle contains the most abundant thorium veins. Veins that contain copper but no thorium also exist, as well as barren quartz veins. Staatz estimates the

FIGURE 2.1. Map Showing the Locations of Promising Thorium Deposits in the United States

thorium reserves at 67,700 tons of ThO_2 with an additional 120,000 tons of probable and potential resources.⁽³⁾ Ten veins within the district contain 94% of these reserves.

The thorium content of some of the better-explored thorium veins ranges from 0.001% to 16.3% with an average ThO_2 content of 0.4%; the grade varies considerably within the veins. Although the overall rare earths content is about equal to the thorium content, the ratio of rare earths to thorium may range from 0.5:1 to 5.2:1 in the same vein.

2.1.3 Wet Mountain

Thorium has been identified in over 400 narrow, steeply dipping veins in a 22-mile tract of Precambrian rocks on the flank of Wet Mountain in Colorado.^(2,4,5)

The thorium-bearing mineralization has been described as a "thorite-like mineral" and is presumed to be thorite. The ThO_2 content of these vein deposits ranges from 0.02% to 12.5% with an average ore grade of 1.1%. Staatz has estimated the size of these reserves at 66,900 tons of ThO_2 . The total probable potential resource in this district is 158,000 tons,⁽³⁾ or 46.9% of the total reserve in identified vein deposits in the U.S.

2.1.4 Hall Mountain, Idaho

Hall Mountain is located approximately 3 miles east of the U.S. border station at Porthill, Idaho.⁽⁶⁾ Thorium has been identified in 11 narrow, steeply dipping veins in a half-sq. mile area. The thorium-bearing mineralization, mainly thorite, is erratic and commonly occurs along fractures. Based on geological and sample data published by Staatz, the minable ore reserve is estimated at 5210 tons of ThO_2 with an average ore grade of 1.3%. The probable potential resource in this district is 29,900 tons.⁽³⁾ This area has 3.7% of the total identified vein deposits in the U.S.

2.1.5 Palmer, Michigan

The Palmer area is located in the east-central portion of Marquette County on the northern peninsula of Michigan. The deposit occupies approximately 3 sq. miles and includes the town of Palmer. The Palmer area is characterized by relatively rugged knobby topography covered by a dense forest.

Thorium-bearing Goodrich quartzite forms the bulk of the ore deposit. This deposit contains an estimated 193,000 tons of ThO_2 . The thorium content is estimated at 1.06 lb/ton (0.06%) but ranges from 0.26 to 3.56 lb/ton⁽⁷⁾ while the average monazite content is estimated at 14.7 lb/ton. The monazite is assumed to be 8.2% thorium oxide.

The other heavy minerals associated with the quartzite are mainly hematite, magnetite, ilmenite, and rutile. No estimates of the amount of these minerals are available. The rare-earth oxide content of the monazite is approximately 46%.⁽⁸⁾ Thus, the amount of minable rare-earth oxides contained in the monazite at Palmer is estimated at over 1,000,000 tons.

2.1.6 Bald Mountain

Bald Mountain is located approximately 6 miles north of Sundance, Wyoming, in the Bear Lodge Mountain area (see Figure 2.1). Microscopic examination of 1400 lb of drill core from Bald Mountain showed that the principal constituents are quartz and feldspars with lesser concentrations of garnet, hematite, limonite, magnetite, ilmenite, zircon, and monazite.⁽⁹⁾ The monazite in 20 million tons of material is reported to average 2.5 lb/ton of ore. A small but high-grade stratum contains 675,000 tons of ore with an average of 13.2 lb of monazite per ton.⁽¹⁰⁾ For purposes of this study, however, the monazite is assumed to be evenly distributed throughout the rock. The average grade of the monazite is reported to be 8.8% ThO_2 .⁽⁹⁾ The Bald Mountain deposit's average ore grade is assumed to be 0.013% or approximately 2.85 lb of monazite per ton of ore. Bald Mountain contains approximately 2600 tons of ThO_2 . Other by-products include as much as 7,700,000 tons of elements and 16,000 tons of rare-earth oxides.⁽¹¹⁾

2.1.7 Conway Granite

The Conway granite of New Hampshire is a large potential source of ThO_2 . The deposit, occupying approximately 307 sq. miles in the White Mountains (see Figure 2.1), contains an estimated 35 million tons of thorium and extends to a depth of at least 1000 ft. Thorium is distributed evenly in the outcrop with an average grade of 56 ± 6 ppm (0.006%) ThO_2 .^(12,13)

Uranium is associated with the thorium. The uranium content is at least one-fourth that of the thorium content.

2.1.8 Bear Lodge

The Bear Lodge deposit--located about 6 miles north of Sundance, Wyoming, and occupying 1.5 sq. miles--contains about 228,000 tons of thorium oxide reserves. Disseminated veinlets of thorium occur in iron-manganese zones. The grade of rock containing the veinlets ranges from 46 ppm ThO_2 to 1,200 ppm ThO_2 . The principal identified thorium-bearing minerals are brockite, monazite, and thorite. The mineralization also contains rare earths at concentrations ranging from 12,000 to 18,000 ppm total rare-earth oxides.

2.2 MINING PROCESSES

2.2.1 Underground Mining

Underground mining is being utilized to develop the Lemhi Pass, Hall Mountain, and the Wet Mountain thorite deposits. The major steps in underground mining are discussed in the following sections.

2.2.1.1 Drilling and Blasting

Blast holes are wet drilled into the working face using pneumatic drills, loaded with explosives, and detonated. Detonation is usually at the end of each shift when miners are out of the work areas.

2.2.1.2 Loading and Transporting Rock to Surface

At the beginning of the following shift, broken rock is removed from the working face. A slusher draws the broken rock into a chute. The rock falls down the chute and is loaded by gravity feed into ore cars positioned on the haulage level. When the working face and ore haulage are on the same level, the ore is loaded into the ore cars using a mucking machine. The loaded ore cars are pulled by locomotive to a dump station outside the mine.

2.2.1.3 Ground Support

After the broken rock is removed from the working area, support is provided, if necessary, by either installing rock bolts or, in the case of weak

2.3 MILLING PROCESSES

The milling processes can be divided into three groups: thorite, conglomerate, and granite processing. The stockpiled deposits do not need to be milled, only refined. The Bear Lodge deposit has not been studied in as detailed a fashion as the other deposits because of 1) a lack of information concerning the processing of this type of ore; and 2) it was not included as a deposit until late in the study. It has been estimated that the Bear Lodge ore would only need to be milled, similar to the thorite ore. Details of the other milling processes are presented below.

2.3.1 Thorite Processing Stream

The conceptual thorite milling process was developed based on a laboratory-scale process developed by the U.S. Bureau of Mines.⁽¹⁴⁾ Thorite is milled by grinding the ore and leaching it with acid. After solvent extraction and ammonium hydroxide precipitation, the precipitate is calcined, producing reactor-grade thorium oxide.

The thorite milling process is utilized to process ores at Lemhi Pass, Hall Mountain, and Wet Mountain. The major process steps are described in the following sections. A flowsheet is contained in Appendix D.

2.3.1.1 Run-of-Mine Storage

Ore arrives at the mill by truck and is stored in piles according to grade. The ore is blended before processing to provide a constant grade for mill input. Front-end loaders transfer the ore from the storage areas to the conveyor.

2.3.1.2 Crushing and Grinding

The conveyor discharges the ore into a jaw crusher, which is in series with a cone crusher. The minus 1 in. discharge from the cone crusher is transferred to temporary storage bins. From there, the crushed ore is ground to minus 35 mesh in two 8 ft x 8 ft ball mills. After grinding, the ore is mixed with water and transferred to the leaching tanks.

2.3.1.3 Leaching

Slurry from the grinding circuit is fed directly into the first of a series of stainless steel tanks equipped with steam heaters to maintain a

ground, timber sets. Unmined pillars of waste rock or low-grade ore are often left to provide support also. Waste rock or sand fill may be brought into mined-out areas for additional support, depending on the mining method.

2.2.1.4 Loading and Scanning of Rock

Ore is loaded from skips into dump trucks on the mine surface. The dump trucks are driven through a scanner to determine ore grade then routed to the mine storage pad. Periodically, the ore is loaded from mine storage and transported to the mill.

2.2.2 Surface Mining

Surface mining techniques would be utilized to develop the Palmer, Michigan; Bear Lodge, Wyoming; Bald Mountain, Wyoming; and Conway Granite deposits. The major process steps are reviewed in the following sections.

2.2.2.1 Removing the Overburden

Approximately 30 ft of overlying till must be removed before mining. The till is scraped using bulldozers, and the overburden is loaded into trucks using the front-end loaders. The overburden is then hauled to a dump adjacent to the pit. The ore is now ready to be mined.

2.2.2.2 Drilling and Blasting

Blast holes are drilled into the ore, using a downhole hammer. The blast holes are loaded with explosives and detonated.

2.2.2.3 Loading the Ore

The ore is loaded into 120-ton electric wheel trucks using 15-yd³ shovels. Fifteen cubic yard front-end loaders are also provided to clean up around the shovels.

2.2.2.4 Hauling of Ore

The electric ore trucks transport the ore to a concentrator located approximately one-half mile from the mine. The truck is routed through a scanner to determine ore grade before it is unloaded.

temperature of 80°C. The slurry is mixed with sulfuric acid and agitated for about 2 hr.⁽¹⁴⁾ The sulfuric acid dissolves the thorium, as well as impurities in the ore. The sulfuric acid consumption, which is a function of the ore grade and the soluble impurities, can vary from 370 lb/ton to 650 lb/ton of ore.

2.3.1.4 Countercurrent Decantation

The leach liquor contains approximately 60% solids, which must be removed before the solvent extraction. This is accomplished in a five-stage counter-current decantation process. A flocculant is added to increase the settling rate of the solids. The underflow from the fifth thickener goes to the tailings pond. For a 2-hr settling rate, a settling area of 22 ft²/ton/day is required for the thickener.⁽¹⁴⁾ Final clarification is accomplished using a leaf-type pressure filter with a vacuum of 15 in. of mercury.

2.3.1.5 Amine Extraction

Thorium is extracted from the leach liquor by an organic solvent containing 10% primary amine, 5% primary decyl alcohol, and 85% kerosene. The leach liquor and organic solvent are brought into contact in seven 5,000-gal mixer/settlers for 15 min.⁽¹⁴⁾ The organic losses are estimated to be 0.5 gal/ton processed per hr.⁽¹⁴⁾ After the thorium is extracted from the leach liquor, the leach liquor is sent to the tailings pond and the organic solution is pumped to the salt-stripping process.

2.3.1.6 Salt Stripping

The thorium is stripped from the organic solution using a premixed salt solution containing 1.5 M NaCl and 0.5 M HCl.⁽¹⁴⁾ The organic and the salt solution are brought into contact in stainless steel agitated tanks. The salt solution removes the thorium from the organic, then the organic is returned to the extraction step. The salt solution, containing thorium, is pumped to the reduction and neutralization process.

2.3.1.7 Reduction and Neutralization

The salt solution is neutralized with soda ash in agitated tanks to remove the thorium, and sodium hydrosulfide is added to reduce ferric

iron.⁽¹⁴⁾ The precipitate is dewatered using a disk centrifuge. The filtrate is discarded to the tailings pond.

2.3.1.8 Caustic Digestion

The dewatered precipitate is pumped to agitated tanks where the precipitate is digested with caustic soda at ambient temperature. A 2-hr residence time is required, and approximately 3 lb of sodium hydroxide are used for each ton of ore.⁽¹⁴⁾ The caustic digestion forms thorium hydroxide, which is removed from the caustic solution by filtration with a continuous rotary-drum filter. The filter--sized at approximately 4 ft² of filter area for each ton/hr processed--yields a precipitate containing 70% solids. The filtrate is pumped to the tailings pond, and the cake is discharged to a conveyor belt.

2.3.1.9 Drying and Ignition

The hydroxide cake is dried to a moisture content of 10% in a twin-screw dryer. The dryer operates with a jacket temperature of 120°C and a screw temperature of 154°C. The twin-screw dryer is discharged to a rotary kiln where the thorium hydroxide is converted to thorium oxide. The kiln operates at 900°C.⁽¹⁴⁾ The kiln was sized by assuming that, in normal operation, 7% of the kiln's volume is filled with thorium hydroxide. The rotary kiln discharges thorium oxide of 99+% purity, which is packaged in drums for shipment to the fuel fabrication facility.

2.3.2 Conglomerate Processing Stream

The conceptual conglomerate monazite processing stream was developed on a laboratory scale by the U.S. Bureau of Mines.⁽⁹⁾ In conglomerate deposits, the mineral monazite is dispersed in rock. The ore is ground to release the monazite. The ground rock is then submitted to gravity and magnetic separation to separate the monazite from the gangue rock. The concentrate is then sent to a refinery (Section 2.4).

The principal deposits studied are Palmer, Michigan, and Bald Mountain, Wyoming. Major process steps are described in the following sections. A flowsheet is contained in Appendix D.

2.3.2.1 Run-of-Mine Storage

Ore arrives at the mill by truck and is dumped in a storage area. The ore is segregated according to grade, blended to maintain a relatively constant input to the mill, and then transferred from the storage area to the primary crusher/conveyor by means of a front-end loader.

2.3.2.2 Crushing and Grinding

The ore is initially crushed in a primary crusher and then transferred to the secondary crusher, which grinds the ore to minus 20 mesh. The discharge is screened, and the oversized particles are returned to the secondary crusher. The processed ore is stored in a crushed-ore bunker.

2.3.2.3 Gravity Separation

The crushed ore is mixed with water and is pumped to a rougher shaking-table circuit. The tails are discarded to the tails pond while the milling product is processed in the scavenger shaking-table circuit. The scavenger shaking-table concentrate is returned to the rougher circuit for reprocessing. The rougher circuit concentrate is transferred to the wet-concentrate storage pile for dewatering.

2.3.2.4 Drying

The wet concentrate is transferred from the wet-concentrate storage to a rotary dryer using an overhead crane. The concentrate is dried and discharged to the magnetic separator conveyor belt.

2.3.2.5 Magnetic Separation

The dry concentrate is processed by rougher cross-belt magnetic separators. The tails from the rougher magnetic separator are processed by smaller scavenger magnetic separators in parallel. The tails are discarded while the concentrate is recycled to the rougher magnetic separator. The final concentrate obtained is discharged to storage until it is shipped to the refinery.

2.3.3 Granite Processing Stream

In the U.S., granite is not currently recovered for ThO_2 . Laboratory beneficiation studies reveal that treating granite directly with sulfuric acid

yields good results.^(12,13) The concentrate obtained is purified by solvent extraction and precipitated with ammonium hydroxide. The concentrate is packaged and sent to a refinery for further purification (Section 2.4). The only granitic deposit studied is located in Conway, New Hampshire. The major process steps are described in the following sections. A flow diagram is shown in Appendix D.

2.3.3.1 Crushing and Grinding

The mined ore is crushed to 8 in. in large gyratory crushers. The crushed ore is transported to outside stockpiles, which hold about an 8-hr supply of granite. The ore is then fed to dry, autogenous, aerofall-type mills where it is ground to minus 20 mesh.

2.3.3.2 Acid Leaching

The ground ore is agglomerated in rotating drums with 20 to 60 lb of sulfuric acid per ton of ore to produce a mix that contains 85% solids, conveyed to concrete vats, and cured for 1 to 5 hr. The ore is washed with recycle process solutions in the vats to obtain a thorium and uranium solution. The relatively small high-acid portion of the wash solution, which is obtained first, is recycled to the agglomeration operation. The next portion of the wash cycle is the pregnant liquor, which is transferred to the solvent extraction step. The latter portion of the wash solution, with a much lower concentration of thorium and uranium, is recycled to wash subsequent batches of ore. A final flush solution--containing ore tailings and water--goes then to lime neutralization and waste disposal.

2.3.3.3 Solvent Extraction

The pregnant liquor goes to a two-stage solvent extraction section. The solvent consists of 0.01 M 1-nondecylamine and 0.01 M N-benzyl-1-(3-ethylpentyl)-4-ethyloctyl amine in a diluent consisting of 99% kerosene and 1% tri-decanol. Thorium and uranium are then costripped from the extract with a 0.25 M Na_2CO_3 solution in two stages. The extraction and stripping operations are performed by standard mixer/settler equipment.

2.3.3.4 Packaging

The thorium and uranium precipitate is filtered, dried, and stored for further refinement and separation.

2.4 REFINING PROCESSES

2.4.1 Stockpiles

The conceptual stockpiled sludge refinery utilizes solvent extraction to purify the ThO_2 . The thorium is precipitated as an oxalate and calcined to produce reactor-grade ThO_2 . The major process steps are described in the following section. A flow diagram is shown in Appendix D.

2.4.1.1 Feed Preparation

Sludge is dissolved in acid to obtain a solution containing 200 g/l ThO_2 . Metallic iron is then added and allowed to dissolve slowly to hinder the formation of thorium phosphate complexes. When the addition of iron is complete, nitric acid is re-introduced to achieve a concentration of 4 M free nitric acid. Large particles of gangue material are removed before the feed enters the solvent extraction unit.⁽¹⁵⁾

2.4.1.2 Solvent Extraction

Thorium is extracted from the acid solution using an organic solvent that contains a 50% solution of tributyl phosphate (TBP) in kerosene. The leach liquor and organic solvent are brought into contact in a 10-stage mixer/settler cascade. As the aqueous phase moves along, it loses uranium and thorium and is discharged as raffinate. The loaded solvent is then scrubbed with nitric acid and pumped to the salt-stripping process.⁽¹⁵⁾

2.4.1.3 Stripping

The thorium solution is contacted with a 1.02 M solution of nitric acid. The thorium is removed, then the freed organic is passed on for uranium recovery. The thorium-bearing aqueous stream is discharged with a concentration of 50 g Th/l.⁽¹⁵⁾

2.4.1.4 Uranium Recovery

The solvent phase is treated with sodium carbonate to remove the uranium, reacidified, and recycled. The uranium-bearing solution is sent to a tailings pond.

2.4.1.5 Concentration

A primary and secondary evaporative system is used to concentrate the thorium nitrate solution. The feed stream enters a secondary evaporative system, which consists of three boildown tanks, that concentrates the solution to about 50% of the original volume. The stream is further concentrated in a continuous single-effect evaporator to a concentration of 0.53 lb Th/l.⁽¹⁶⁾

2.4.1.6 Precipitation

The thorium nitrate solution is mixed with nitric acid and heated to 45°C with steam. Oxalic acid is added and the solution is agitated for several minutes to facilitate the precipitation of thorium oxalate.⁽¹⁶⁾

2.4.1.7 Filtration

The slurry is filtered in a rotary vacuum filter, and an oxalate cake containing 30% to 35% water by weight is discharged. The filtrate is pumped to a plate-and-frame filter press for further clarification and then neutralized with a solution of sodium carbonate. The spent filtrate combines with the raffinate prior to liquid waste treatment.⁽¹⁶⁾

2.4.1.8 Drying

The oxalate cake is dried to a 10% moisture content--to avoid spattering in the calciner--in a twin-screw dryer with a jacket temperature of 120°C and a screw temperature of 154°C. The thorium oxalate with a bulk density of approximately 45 lb/ft³ ⁽¹⁶⁾ is discharged into a variable-speed auger.⁽¹⁷⁾

2.4.1.9 Calcination

The oxalate cake is calcined to thorium oxide in an externally fired rotary kiln for 2 hr. Gas flowing countercurrently exits at a temperature of 820°C. The thorium oxide product is a light, finely divided powder.⁽¹⁷⁾

2.4.1.10 Packaging

The thorium oxide is packaged in 55-gal drums for storage or shipment.

2.4.2 Conglomerates

The conceptual conglomerate refining process consists of acid leaching followed by solvent extraction, caustic digestion, precipitation, and calcination.⁽⁹⁾ The process recovers 95% of the ThO_2 and produces a product of 99+% purity. The major process steps are discussed below. A flow diagram is shown in Appendix D.

2.4.2.1 Grinding

The concentrate arrives from the mill by truck and is stored until processing. The concentrate, which has already been crushed to 20 mesh, contains between 1% and 6% thorite. Before leaching, the concentrate is dry ground to 100 mesh in a ball mill.

2.4.2.2 Leaching

The concentrate is mixed with 1.5 times its weight of 96% H_2SO_4 and heated to 200°C in agitated tanks for 2 hr. The concentrate is then mixed with 5 parts water and agitated for 1 hr. The pregnant solution is filtered and washed with acidified water.⁽⁹⁾

2.4.2.3 Liquid/Solid Separation

After the acid leaching process, the pregnant solution contains 6% solids. It is flocculated with 0.2 lb of flocculate per ton of concentrate then filtered using a leaf-type pressure filter. The pregnant liquor is then transferred to the solvent extraction process.

2.4.2.4 Solvent Extraction

Thorium in the pregnant leach liquor is extracted using an organic solvent with 10% aliphatic primary amine, 5% primary decyl alcohol (PDA), and 85% kerosene. The leach liquor and the organic solvent are brought into contact in the mixer/settler for 15 min. The organic solution extracts the thorium from the pregnant leach solution. The barren leach solution (raffinate) is then discarded. The loaded organic is scrubbed in mixer/settlers with 0.2 M sulfuric acid to remove the dissolved rare-earth oxides.⁽⁹⁾

2.4.2.5 Salt Stripping

A salt solution is used to strip the thorium from the loaded organic. The loaded organic and the salt solution are brought into contact in three stainless steel agitated tanks. The premixed salt solution, containing 1.5 N sodium chloride and 0.5 N hydrochloric acid solution removes the thorium from the organic, which is returned to the amine extraction step, in one agitated tank. The loaded strip liquor is pumped to the neutralization process.⁽⁹⁾

2.4.2.6 Neutralization

The loaded strip liquor is neutralized, forming hydrous sodium and thorium sulfates, which precipitate out of solution.⁽⁹⁾ The barren strip liquor is then neutralized with soda ash in an agitated tank. The precipitate is dewatered using a rotary-drum filter.

2.4.2.7 Caustic Digestion

The dewatered precipitate is transferred to an agitated stainless steel tank where the precipitate is digested with caustic soda at room temperature. The caustic digestion forms hydrous thorium oxide, which is removed from the caustic solution with a continuous rotary-drum filter.⁽⁹⁾

2.4.2.8 Drying and Ignition

The hydrous thorium oxide is dried to 10% moisture content in a twin-screw dryer, which operates with a jacket temperature of 120°C and a screw temperature of 154°C. The twin-screw dryer discharges thorium hydroxide into a rotary kiln where it is converted to thorium oxide. The kiln operates at 850°C and runs 7% full.⁽¹⁸⁾ The rotary kiln discharges thoria of 99+% purity. The thoria is packaged in drums and shipped to the fabrication facility.

2.4.2.9 By-Product Recovery

The raffinate from the solvent extraction phase contains the dissolved rare-earth oxides. To precipitate the rare earths, 60 g/l of sodium sulfate is added to the raffinate. Ninety-eight percent of the rare-earth by-products are converted to the sulfate salt. The rare-earth sulfates are treated with

caustic soda, and a rare-earth hydroxide precipitate is formed. The precipitate is dried at 140°C. Product purity is estimated at 46% rare-earth oxides (REO).⁽⁹⁾

2.4.3 Granite

The conceptual granite refinery would be similar to the reference stockpile refinery except for the addition of an extraction cascade, which precedes the ThO₂ extraction steps (see Section 2.4.1.1). The 10-stage cascade uses a 5% tributyl phosphate solvent to remove uranium from the thorium solution. The uranium recovery steps are discussed below.

2.4.3.1 Uranium Recovery

The thorium-uranium solution enters a 5-stage solvent extraction section where the aqueous is contacted with a 5% solution of TBP in kerosene. The thorium-bearing aqueous continues on to the next solvent extraction section. The organic solution enters a 5-stage scrub section where the uranium is removed from it using an aqueous 4 N nitric acid solution. The uranium solution is precipitated with ammonia, dewatered, and dried. The stripped organic solvent is recycled.⁽¹⁷⁾

2.5 PRODUCTION COSTS

Production costs for developing domestic thorium resources range from \$3 to \$60 per lb of thorium oxide (ThO₂). The supply curve (Figure 2.2A and B) illustrates the quantity of thorium available at a given production cost. All of the costs are in 1978 dollars. The production cost figures include baseline environmental control costs (discussed in Chapter 3), which are no more than 10% of the production cost (see Table 2.1) and, thus, have little effect on the cost of thorium oxide. The supply is discussed in more detail in a previous report.⁽¹⁹⁾

The low-cost resources that would be developed to satisfy near-term thorium oxide demands include the stockpiles in Fernald, Ohio; Miamisburg, Ohio; and Curtis Bay, Maryland, and the thorite deposit at Hall Mountain, Idaho. Approximately 8,000 tons of thorium oxide are available from these resources

FIGURE 2.2A Domestic Thorium Oxide Supply Curves

FIGURE 2.2B Domestic Thorium Oxide Supply Curves

TABLE 2.1. Summary of Thorium Production Costs and Reserve Estimates

Resource	Production Costs (\$/lb)		Quantity Recovered Tons ThO ₂	Estimated ^(a) Quantity Tons ThO ₂ In Deposit	Estimated Minimum Environmental Control Cost (% of Total Cost)
	Most Likely	Range			
Fernald	5.80	4.30 to 8.50	1,500	1,500	2.6%
Miamisburg	4.60	2.86 to 5.58	800	800	3.7%
Curtis Bay	4.60	2.86 to 5.58	400	400	3.7%
Chattanooga	5.80	4.30 to 8.50	360	360	2.6%
Lemhi Pass	15.73	10.80 to 22.90	9,800	187,000	4% to 5.2%
	12.10	8.91 to 17.40	14,000		
Hall Mountain	6.30	5.60 to 9.30	5,000	35,000	4.4%
Wet Mountain	8.30	5.92 to 13.30	61,000	224,900	4.1%
Palmer	14.20	9.90 to 17.10	70,000	193,000	3.2%
Bear Lodge	57.43	34.20 to 84.90	137,000	1,620,000	Unknown
Bald Mountain	49.00	29.00 to 68.00	2,600	Unknown	8.8%
Conway Granite	59.32	36.70 to 93.70	U ^(b)	35,000,000	0.72%

(a) Includes probable and potential reserves.

(b) Uncertain, depends on maximum demand.

at a cost below \$10 per lb. These resources could adequately supply the thorium oxide for prototype purposes and for the initial commercialization of the thorium fuel cycle.

Over the longer term, thorium deposits at Wet Mountain, Colorado; Lemhi Pass, Idaho; and Palmer, Michigan would be developed. These deposits represent approximately 160,000 tons of thorium oxide. These resources could support thorium reactor growth and development for at least the next 50 yr under the most likely conditions with costs ranging from \$8 to \$17 per lb of thorium oxide.

Low-grade deposits of thorium at Bald Mountain, Wyoming; Bear Lodge, Wyoming; and Conway Granite, New Hampshire could support a thorium fuel cycle for hundreds of years at costs approximately equal to or exceeding \$50 per lb of thorium oxide. These deposits represent over 17 million tons of thorium oxide.

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3.0 ENVIRONMENTAL IMPACTS FROM THORIUM PRODUCTION

3.1 CURRENT PRODUCTION⁽¹⁾

The only domestically produced thorium at the present time is from monazite sands dredged in Florida. The thorium and rare earths are extracted in Chattanooga, Tennessee, and the thorium is refined in Jonesboro, Tennessee. Currently, only 20,000 lb/yr of reactor-grade thorium oxide (99+%) are domestically produced.

Because the beach placer deposits of Florida, which yield monazite sands, are too low-grade to be economically mined for thorium alone, thorium is produced as a by-product only and the amount produced is dependant on the market for rare earths. For these reasons, the Florida placer deposits were not included in the supply curves presented in Chapter 2. The wastes generated by a typical placer-mining operation were compiled in An Assessment of U.S. Domestic Capacity for Producing Reactor-Grade Thorium Dioxide and Controlling Associated Wastes and Effluents, PNL-2593, by W. I. Enderlin.⁽¹⁾ This report was used to evaluate the generated wastes from the current production processes. The environmental control costs associated with the mining, milling, extraction, and refinement of thorium dioxide presented below are estimates based on state-of-the-art technology, which may be different from what is presently used.

Table 3.1 is a summary of the estimated environmental control costs for mining, milling, extracting, and refining thorium dioxide from monazite sands. For both capital and annual costs, the generated wastes from the mining and milling operation are the most expensive to control. As noted in Table 3.1, the unit costs of environmental control assumes that the various by-products will receive no credit. The major capital costs are for the various ponds and basins used to settle and store the liquid and solid wastes. A detailed description of the generated wastes and the estimated costs of controlling them are presented in Sections 3.1.1 through 3.1.3 for current production methods.

TABLE 3.1. Summary of Environmental Control Costs Using the Current Level of Control and Size of Operations

Operation	Capital Cost of Facilities Total (\$1000)	Total ^(a) Annual Cost (\$1000)	Approximate Thoria Production (ton/yr)	Environmental Control Unit Cost ^(b) if Thoria is Sole Product
Mining and Milling ^(c)	\$2,569	\$1,279	16	\$39.97/lb ThO ₂
Extraction ^(d)	\$ 295	\$ 157	500	\$0.16/lb ThO ₂
Refining ^(e)	\$ 161	\$ 92	100	\$0.46/lb ThO ₂

(a) The total annual cost is the operating cost plus the annualized capital cost. A fixed charge rate of 0.2441 is assumed to apply to depreciable capital and a 0.05 charge rate is assumed to apply to land and working capital.

(b) The unit cost is the cost if thorium carries the full burden of the environmental control costs. If rare earths, titanium, and other products receive credit, this cost will be reduced commensurately.

(c) Based on the dredge mining in Florida.

(d) Based on the rare earth processing plant in Chattanooga, Tenn.

(e) Based on the thorium refinery in Jonesboro, Tenn.

3.1.1 Mining and Milling

The main wastes stream generated by the mining and milling processes are shown in Figure 3.1. The processes are divided between dredging operations, the wet mill, and the dry mill. In dredging and wet milling, the major wastes--wet tailings and mine water--are sent to the dredge pond. From the dredge pond, part of the water is reused in the dredging operation and the rest is treated, settled, and discharged to a river.

The dry mill uses a variety of techniques to separate the heavy metals, monazite sand, and other products from the gangue materials and each other. The dry mill tailings are the most radioactive of the wastes generated. At this time, the only environmental control procedure consists of simply burying the tailings. In the future, these tailings may be recycled and reworked to extract the remaining monazite. The dry mill also emits fugitive dust. While not as highly radioactive as the tailings, this dust is controlled by a variety of means including general ventilation with fans and cyclone dust collectors.

The environmental control methods and costs for mining and milling monazite sands in existing operations are shown in Table 3.2. The six basins and holding ponds needed for the liquid and solid wastes account for more than half of the capital costs. When the plant ceases operation, the ponds will have to be rehabilitated at a cost of \$360,000 for 180 acres.

The equipment shown in Table 3.2 is actually being used for environmental control but the cost figures are not precise because the unconventional type of equipment used was custom built. The control equipment meets current state and federal environmental standards but will have to be updated or replaced if stricter EPA regulations are established.

3.1.2 Extraction of Thoria

A caustic soda attack process, shown in a simplified form in Figure 3.2, is used to concentrate the 3.8% thorium dioxide or thoria in the 95% monazite sand entering the facility to 25% ThO_2 in the thorium pond sludge. In this process, the monazite sand reacts with hot caustic soda to produce phosphate

FIGURE 3.1. Main Effluents Emitted from Mining and Milling Processes

TABLE 3.2. Estimated Costs of Environmental Control Facilities and Operations for Existing Monazite Sand Mining and Milling Operations

Capital Cost Summary

<u>Liquid and Solid Wastes</u>	1978 Installed Cost ^(a) (\$1000)
Two 3000-gpm Pumps	\$ 130
Surge Storage Basin	108
Rapid Mix Basin	54
Slow Mix Basin	405
Two Intermediate Holding Basins	108
pH Adjustment System	108
Large Settling Pond (170 acres)	510
Pipe and Ditches	281
Auxiliary Facilities	216
	<u>\$1,920</u>
<u>Airborne Wastes</u>	
Fans	\$ 30
Cyclone Dust Collectors	83
	<u>\$ 113</u>
<u>Contingency, Fees, and Land</u>	
Total Installation Cost	\$2,033
10% Contingency	203
Subtotal	<u>\$2,236</u>
5% Contractor Fee	112
	<u>\$2,348</u>
180 Acres of Land	216
Total Capital Cost	<u>\$2,564</u>

Annual Operating Cost Summary

Capital Charge	\$ 626
Land and Working Capital Charge	31
Maintenance	74
Operations and Overhead	49
Chemical Costs	
Alum	97
Caustic	259
Miscellaneous	54
Power Cost	35
Miscellaneous Supplies	54
Total Annual Operating Cost	<u>\$1,279</u>

Rehabilitation Cost Estimate

Rehabilitate 180 Acres @ \$2,000/acre	\$ 360
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(a) Includes complete installation as well as engineering and construction overheads.

FIGURE 3.2. Main Effluents Emitted from Extraction Process

and a mixed thorium rare-earth hydroxide. Acids are used to split the hydroxide. There are two streams from this process: thorium and gangue materials in the "waste" stream, which are pumped to the thorium pond, and the rare earths in the product stream.

The major wastes generated in the caustic recovery system are controlled in ponds. In this system, thorium oxide and other liquid wastes are stored in two ponds--the phosphate pond and the main pond. The thorium pond is the repository of the product sludge, which contains the majority of the radioactive substances. The pond systems, as shown in Table 3.3, are the most expensive items used for environmental control. They cover 12 acres of land and, with the price of rehabilitating the land, cost \$264,000, which does not include the annual capital charge for the ponds.

The extraction process also produces dust. The ball mill is the major point of dust emission but the storage area at the beginning of the processing also has some fugitive dust emissions. The dust emission control system consists of fans and a dust collector, and, in the areas where caustic or acidic solutions are used, fume scrubbers are needed.

The location of solid waste disposal is one problem that may arise. Many states have now banned the permanent disposal of low-level radioactive substances. If these solids must be packaged for disposal offsite, the cost of onsite rehabilitation may be less than shown but the transportation costs would make this a more expensive option.

3.1.3 Thoria Refinement Plant

Sludge in the thorium pond at the extraction plant is refined in a refinement plant to obtain a thorium dioxide product (99+% ThO_2). The thorium dioxide refinement process, shown in Figure 3.3, uses solvent extraction to separate thorium from the gangue and rare earths. The solvent extraction and thorium oxalate filtration sections of the process generate both liquid and solid wastes. Only one 1.5-acre waste pond is needed for the liquid and solid wastes because the sludge from the filtration unit is shipped offsite for burial at a licensed low-level burial site.

TABLE 3.3. Estimated Capital, Annual, and Rehabilitation Costs for Environmental Control Facilities and Operations for the Extraction of Thoria from Monazite in Existing Operations

Capital Cost Summary

<u>Liquid and Solid Wastes</u>	1978 Installed Cost ^(a) (\$1000)
1.75-acre Thoria Pond	\$ 22
3-acre Phosphate Pond	33
7-acre Main Settling Pond	59
Piping System	22
pH Control	11
Auxiliary Facilities	11
	<u>\$158</u>
<u>Airborne Wastes</u>	
Two 10,000-cfm Fans	14
Two 10,000-cfm Plant Air and Fume Scrubbers	43
One 1500-cfm Fan and Dust Collector	14
	<u>\$715</u>
<u>Contingency, Fees, and Land</u>	
Total Installation Cost	\$229
10% Contingency	23
Subtotal	<u>\$252</u>
5% Contractor Fee	13
	<u>\$265</u>
12 Acres of Land	30
Total Capital Cost	<u>\$295</u>

Annual Operating Cost Summary

Capital Charge	\$ 72
Land and Working Capital Charge	4
Maintenance	9
Operating and Overhead	7
Carbon Dioxide	54
Power	8
Miscellaneous Supplies	6
Sewer Fee	6
	<u>\$166</u>

Rehabilitation Cost Estimate

Rehabilitate 12 acres @ \$10,000/acre	\$120
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(a) Includes complete installation plus engineering and construction overhead.

FIGURE 3.3. Current Thorium Dioxide Refining Process

The thoria refinement plant also produces some airborne wastes from calcination and thoria packaging. Dust and fumes are the major emissions. The amount of money spent for environmental control of airborne wastes at the thoria refinement plant is about the same as for liquid and solid waste control, as shown in Table 3.4. These control costs show that the more radioactively concentrated the dust becomes, the more costly the control methods are. Every point of dust release in the refinery must have some sort of dust collection system.

TABLE 3.4. Estimated Costs of Environmental Control Facilities and Operations at a Thoria Refinement Plant

Capital Cost Summary

<u>Liquid and Solid Wastes</u>	1978 Installed Cost ^(a) (\$1000)
Lime Addition Facility	\$ 16
Plate-and-Frame Filter	16
1.5-acre Pond	20
Auxiliary Facilities	13
	<u>\$ 65</u>
<u>Airborne Wastes</u>	
Acid Fume Fan and Scrubber	\$ 22
Fan and Dust Collector	22
Packaging Hood, Fan, and HEPA Filter ^(b)	22
	<u>\$ 66</u>
<u>Contingency, Fees, and Land</u>	
Total Installation Cost	\$131
10% Contingency	13
Subtotal	<u>\$144</u>
5% Contractors Fee	7
	<u>\$151</u>
2 Acres Land	10
Total Capital Cost	<u>\$161</u>

Annual Operating Cost Summary

Capital Charge	\$ 39
Land and Working Capital Charge	2
Maintenance	5
Operating	10
Lime and Miscellaneous Supplies	4
Power and Utilities	2
Package and Ship Filter Cake to Burial	30
Total Annual Operating Cost	<u>\$ 92</u>

Rehabilitation Cost Estimate

Rehabilitate 2 Acres @ \$23,000/acre	\$ 46
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(a) Includes complete installation plus engineering and construction overheads.

(b) High-efficiency particulate air filters (HEPA filters).

All liquid and solid wastes pass through the plate-and-frame process before either storage in the waste pond or transportation to an offsite burial facility. The estimated cost of packaging and shipping the filter cake to this burial facility is \$30,000/yr. After plant operations cease or when the waste pond is full, the residual sludge may have to be packaged and shipped offsite. This cost, which is not included, might exceed \$1,000,000.

3.2 POTENTIAL THORIUM SOURCES

The location and characteristics of various potential domestic deposits of thorium oxide are discussed in Section 2 along with the ore mining, milling, and refinery processes. The costs given for each deposit in Section 2.5 include state-of-the-art environmental control costs. Sections 3.2.1 through 3.2.7 include detailed discussions of the types and levels of generated wastes from each process at each deposit. The costs of state-of-the-art environmental control techniques for each deposit are also presented in the following sections.

The Bear Lodge deposit is not discussed in detail in Section 3 or 5 because of inadequate information on its ore processing and because the information concerning it was received too late to develop a full analysis of the environmental effects.

3.2.1 Stockpiles^(2,3,4)

Only a refinery is required to produce thorium from existing stockpiles. The stockpile refinery (see Appendix D) is designed to process 25% ThO₂ sludge, which is similar to the stockpiled sludge at the W. R. Grace and Company thorium pond in Chattanooga, Tennessee.

The various waste streams and the mass and radioactivity balances for each stream are shown in Figure 3.4. The dust stream from the drying and loading processes is the smallest waste stream, but it needs to be controlled very closely because the activity per unit mass is very high for dust from these processes. The uranium and other rare-earth impurities form another waste stream after their removal. This stream, which also contains the various daughter products of thorium, flows into the tailings pond for storage. These radioactive elements make the waste stream to the tailings pond the most radioactive in the refinery.

FIGURE 3.4. Stockpile Refinery Generated Wastes

At the beginning of the sludge refinement process, nitric acid is added to the entering sludge to form thorium nitrate. However, a large part of the entering sludge does not dissolve and, therefore, must be disposed of. This 80% solids stream must be buried in an approved land site.

The capital and annual costs of controlling the various waste streams are shown in Table 3.5. The waste sludge will be landfilled in a 2.5-acre clay-lined pit. The sludge (solid waste) will be trucked to the site in hoppers for easy handling. Transportation by hoppers is cheaper than using a conveyer system or slurry line. The drying and packaging dust (airborne wastes) will be collected by a 6000-cfm system of baghouse filters and HEPA filters in series. The solids collected from the baghouse filters will be recycled back into the main process stream.

TABLE 3.5. Estimated Waste Control Costs for a Stockpile Refinery

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
Waste Sludge	2.5-acre, clay-lined, landfill pit with trucks & hoppers	157.0	57.6
Liquid Waste	4-acre, clay-lined tailings pond with no recycle system	164.0	43.1
Drying & Packaging Dust	6000-cfm bag & HEPA filter system with demister	104.0	45.5
Tailings Pond Beach Dust	Portable chemical spraying equipment	4.0	2.4
Tailings Pond Radioactivity	6-ft compacted-earth cover with 6 in. rock	70.1	0.7
Total Costs		<u>499</u>	<u>149</u>

The 4-acre, clay-core tailings pond will be the most expensive waste control measure at the refinery. The capital cost of \$164,000 includes the land cost, construction costs, and the distribution system costs. Beach dust from the tailings pond will be minimized by spraying the beach with chemicals to keep the dust level very low and to prevent offsite contamination. As part of the decommissioning of the refinery at the end of its useful life, the pond tailings will have to be covered to contain the radioactive gases and dust.

The total capital cost of waste control for the stockpile refinery is \$500,000 while the annual cost is \$150,000, as shown in Table 3.5. Of the capital costs, $\approx 1/3$ is for waste sludge disposal and $\approx 1/2$ is for the tailings pond, including beach dust control and the pond cover. The above costs may be two to three times higher depending on site- or process-dependent variables.

3.2.2 Lemhi Pass Deposit⁽⁵⁾

3.2.2.1 Mine Generated Wastes

Solid waste generated wastes from the 1,000 ton/day Lemhi Pass mine consists of low-grade wall rock and gangue material. The ratio of waste to ore

is 30 lb of waste rock to 1 ton of ore.⁽⁶⁾ Due to its low-level of radioactivity, the waste rock can be disposal of onsite.

Dust originates at two areas in the mine. It was estimated that approximately one quarter of the dust generated wastes is generated in the underground mine. Most of the dust ($\approx 3/4$) was estimated to originate in the above-ground mine operations, which include loading and transporting the mined ore to the mill and storing this ore.

The dust in the underground mine can be completely controlled by the 300,000-cfm ventilation system required for the miners' health and safety. Dust collectors are not needed because the dust is dilute enough to release directly to the atmosphere. Thus, the cost of dust control in the underground mine is zero. The cost of the ventilation system is included as part of the mine's overall capital cost.

The above-ground dust is controlled by wetting down the roads, yards, and storage piles. To further control the dust, barriers are required around the ore storage piles. The major control costs are for these above-ground dust control measures, as shown in Table 3.6.

The liquid wastes from the mine are influenced by a number of subsurface hydrologic conditions including the proximity of mine shafts to subsurface aquifers and the size of these aquifers. Liquid wastes are assumed to average 500 gpm since the Lemhi Pass mine was assumed to be an intermediate (500 to 2,000 gpm) or dry mine (<500 gpm). The average ThO_2 concentration in the mine water was assumed to be 12.5 ppm. This average was based on the U_3O_8 content in mine water of a number of uranium mines since there are no thorium mines at the present time.

At the Lemhi Pass mine, the mine water is the most radioactive waste. A 2-acre settling pond on a 3-acre tract is needed to control the mine water. Containment in this pond will allow the fines to settle out.

3.2.2.2 Mill/Refinery Generated Wastes

The Lemhi Pass mill/refinery processes 0.356% ThO_2 ore from the Lemhi Pass mine and produces 99% ThO_2 powder. There are three main dust streams

TABLE 3.6. Estimated Waste Control Costs for Lemhi Pass Mine and Mill/Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	2-acre settling pond, ditches, etc.	35.2	11.1
Underground Mine Dust	300,000 cfm ventilation	0	0
Above-Ground Mine Dust	Spray equipment and wind barriers	45.0	34.2
<u>Mill/Refinery</u>			
Dust from Unloading, Crushing, and Grinding	26,000-cfm cyclone system	19.9	11.6
Drying and Ignition Dust	21,000-cfm wet-impingement scrubber system	39.9	20.4
Packaging Dust	4,000-cfm baghouse filter system	22.7	9.9
Liquid Waste	Tailings pond: 100-acre clay-core dam and reservoir with recycle and distribution systems	3,066	913.4
Tailings Pond Beach Dust	Portable chemical spraying equipment	20.0	26.0
Tailings Pond Radioactivity	1-ft compacted earth cover with 6 in. rock	320.0	1.0
Total Costs		<u>3,570.0</u>	<u>1,030</u>

(a) Summarized from Appendices C and E.

and four main liquid waste streams. The detailed calculations of the effluent streams and their levels of radioactivity are shown in Appendix D and summarized in Figure 3.5.

Airborne wastes are released as the ore from the mine is stored in piles according to grade, crushed, and ground. Dust from unloading, crushing, and grinding the ore is released at a rate of 4.55 lb/hr; it has an overall radioactivity rate of 6.9×10^{-6} Ci/hr. The percentage of ^{232}Th in the dust is the same as the overall percentage in the ore being crushed (0.313%). Airborne wastes are released from two other points. The drying and ignition processes release 896 lb/hr of airborne wastes, most of which is water evaporated in the kiln. Even though the amount of dust is small, it is very radioactive on a per mass basis because it is 99% ThO_2 . This is also true of the dust released from the packaging operation. Only 0.02 lb/hr are emitted but the radioactivity per lb is ≈ 58 times higher than the dust from unloading, crushing, and grinding the ore.

The airborne waste streams will be controlled by several methods at varying costs. A system of fans and hoods with a 26,000-cfm capacity and a cyclone dust collector will be used to control the dust from unloading, crushing, and grinding the ore. The capital cost for this system is \$19,900 and the annual cost \$11,600. The cost of controlling the drying and ignition dust is higher because that stream is more radioactive. To control it, fans and a 21,000-cfm wet-impingement scrubber will be installed at a capital cost of \$39,900 and an annual cost of \$20,400. Although the packaging dust stream is smaller and less radioactive than the other streams on a per hr basis, the radioactivity is quite a bit larger on a per mass basis than any of the other streams. Because of this high radioactivity, a system of controlling very small particles is needed. The 4,000-cfm baghouse filter unit with fans and hoods will operate at a higher efficiency to ensure that little of the dust is emitted to the environment. The solids collected from all of the above dust streams are recycled back into the main flow streams.

FIGURE 3.5. Lemhi Pass Mine and Mill/Refinery Generated Wastes

Four liquid streams flow into the central tailings pond. The largest stream is from the counter-current decantation process, and it is 45% solids. The tailings pond receives most of the radioactivity from the mill. Even the final product has less radioactivity than the tailings pond because all of the thorium daughters not emitted in the dust streams are assumed to enter the pond. All of the ^{238}U , ^{235}U , and their daughter products are also impounded in this pond, except for the small amount released in the airborne wastes.

A 100-acre pond is needed to contain the tailings and to allow $\approx 1/4$ of the waste water to evaporate. This pond will have a clay-core dam and will need a system for spreading the tailings that precipitate from the water. There may be some seepage (0 to 15%) even with a clay-core dam. About 75% of the tailings water is recycled through the mill. Before entering the mill, the recycled water will pass through a 1-acre settling pond where the remaining solids will settle out.

A detailed cost breakdown for the above tailings pond system is summarized in Table 3.6. The capital cost of controls is \$3,066,000 and the annual cost is \$913,000. These are the major environmental control costs for the Lemhi Pass deposit; they represent greater than 85% of the total capital and annual costs. The cost of spraying the beach with chemicals and water to control the beach dust will be \$26,000/yr; the spray equipment will cost \$20,000. When the mill is decommissioned, the tailings pond will be covered with 1 ft of earth and 6 in. of rock. This will reduce or eliminate the thoron gas, radioactive dust, and radiation. The tailings pond covering will cost \$320,000 to install and should be sufficient to protect the environment from significant contamination.

The total capital cost of controlling environmental emissions for the entire Lemhi Pass deposit--mining through mill/refining--is \$3,570,000 and the annual cost is \$1,030,000. The cost of the tailings pond for the mill/refinery is $\approx 95\%$ of the capital costs and $\approx 91\%$ of the annual costs, excluding the costs of beach dust control and covering the tailings pond.

3.2.3 Hall Mountain Deposit⁽⁵⁾

3.2.3.1 Mine Generated Wastes

The mine at the Hall Mountain deposit is an underground thorite mine similar to the Lemhi Pass mine. The 1.1% ThO_2 ore grade is higher than the Lemhi Pass ore grade but less ore is mined (400 ton/day). Because of the high ore grade, the dust contains more ^{232}Th at Hall Mountain. It was assumed that $\approx 1/4$ of the dust is from the underground mine and $\approx 3/4$ is emitted above ground, the same as for the Lemhi Pass mine. The waste release rates from the mine operations are shown in Figure 3.6.

The solid wastes removed from the mine--gangue and wall rock--are assumed to be of such low radioactivity that their disposal onsite poses no environmental problems.

The liquid wastes at Hall Mountain are the most radioactive of the effluents released, as was the case with the Lemhi Pass deposit. For liquid wastes, we followed the assumptions used at Lemhi Pass (see Section 3.2.1). The Hall Mountain mine is half as large as the Lemhi Pass mine so the water removal was assumed to be 250 gpm. The average ThO_2 concentration in the mine water was assumed to be 12.5 ppm. There are, as previously mentioned, a number of subsurface conditions that may influence the flow and concentration levels in the mine water.

The mine water is the most radioactive stream from the Hall Mountain mine. To control the mine water and to settle the fines, a 1-acre settling pond is required. The total capital cost of the settling pond and associated equipment is \$21,700 while the annual cost is \$9,700.

Airborne wastes in the Hall Mountain Mine will be controlled by a 160,000-cfm ventilation system. No control measures will be needed for mine dust because it is sufficiently diluted by this system. Thus, the cost of controlling the mine dust is zero, as shown in Table 3.7. The cost of the ventilation system is already included as part of the overall mine cost.

The airborne wastes from the above-ground mine operations are controlled by 1) spraying waste water onto the areas of heaviest dust emissions, and 2) erecting wind barriers. These measures have a capital cost of \$26,000 and an annual cost of \$22,700.

FIGURE 3.6. Hall Mountain Mine and Mill/Refinery Generated Wastes

TABLE 3.7. Estimated Waste Control Costs for Hall Mountain Mine and Mill/Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	1-acre settling pond, ditches, etc.	21.7	9.7
Underground Mine Dust	160,000-cfm ventilation	0	0
Above-Ground Mine Dust	Spray equipment and wind barriers	26.0	22.7
<u>Mill/Refinery</u>			
Dust From Unloading, Crushing, and Grinding	18,000-cfm cyclone system	13.5	10.2
Drying and Ignition Dust	25,000-cfm wet-impingement scrubber system	46.2	30.5
Packaging Dust	4400-cfm baghouse filter system	24.7	14.3
Liquid Waste	Tailings Pond: 15-acre clay-core dam and reservoir with recycle and distribution	970.0	450.0
Tailings Pond Beach Dust	Portable chemical spraying equipment	11.5	16.0
Tailings Pond Radioactivity	1-ft compacted earth cover with 6 in. rock	70.1	10.4
Total Costs		<u>1,180</u>	<u>563</u>

(a) Summarized from Appendices C, E, and F.

3.2.3.2 Mill/Refinery Generated Wastes

The Hall Mountain mill/refinery processes 1.1% ThO_2 ore from the Hall Mountain mine and produces 99% ThO_2 powder. At the Hall Mountain mill/refinery--like Lemhi Pass, there are three dust streams and four liquid effluent streams to be treated. The detailed calculations of the radioactivity of these streams are given in Appendix D and summarized in Figure 3.6.

The three airborne waste streams have varying release rates and levels of radioactivity. The dust from unloading, crushing, and grinding the ore is released at a rate of 1.8 lb/hr and has a radioactive release rate of 9.2×10^{-6} Ci/hr. The percentage of ^{232}Th in this dust is assumed to be the same as that in the ore being crushed (0.968%). The drying and ignition process releases 292 lb/hr of airborne wastes. Most of this is water but the dust given off is 99% ThO_2 . Of the three dust streams, this stream has the highest radioactive release rate (1.3×10^{-5} Ci/hr). The packaging dust is released at a rate of 0.02 lb/hr, is 99% ThO_2 , and has a radioactive release rate of 2.2×10^{-6} Ci/hr.

Each of the three airborne waste streams uses a different type of control. A system of fans, hoods, and an 18,000-cfm capacity cyclone dust collector will be used, to control the dust from unloading, crushing, and grinding. This system will cost \$13,500 installed and \$10,200 to operate annually. The drying and ignition dust stream is the largest and most radioactive of the three dust streams. It is controlled by a system consisting of fans, hoods, and a 25,000-cfm capacity wet-impingement scrubber. The control measures for this stream are the most expensive to purchase, install, and operate, as shown in Table 3.7, with a capital cost of \$46,200 and an annual cost of \$30,500. To control the packaging dust, a small particle control system is needed because of the high radioactivity per unit weight. The stream is small but 99% ThO_2 . The 4400-cfm baghouse filter system has a capital cost of \$24,700 and an annual cost of \$14,300. All of the radioactive solids removed from the dust streams will be recycled back into the mill processes from whence they came.

Four liquid streams flow into the central tailings pond. Most of the ^{232}Th in the tailings pond ($\approx 91\%$) is from the counter-current decantation stream. The tailings pond receives most of the radioactivity from the mill because all of the thorium daughters and uranium products and daughters that are not released in the dust from unloading, crushing, and grinding the ore are impounded in the tailings pond.

A 15-acre tailings pond with a clay-core dam will be needed to allow the tailings to precipitate out and $\approx 1/4$ of the water to evaporate. The other $\approx 3/4$ of the water will be recycled back to the mill after passing through another small settling pond. Because of the clay-core dam, the tailings pond should keep the seepage rate low (0 to 15%). The capital cost for the tailings pond system is \$970,000, $\approx 80\%$ of the total environmental control costs for the Hall Mountain deposit.^(a)

To control the beach dust from the tailings pond, chemicals will be sprayed on the beach. The capital cost for the spray equipment is \$11,500 and the annual cost of the operation is \$16,000. To decommission the tailings pond, a cover must be placed over it. This tailings pond cover will consist of 1 ft of compacted earth and 6 in. of rock. This should be sufficient to stop most radioactivity from seeping through to the atmosphere. The capital cost of this cover is \$70,100.

At the Hall Mountain mine and mill/refinery, the total capital cost for the environmental control of emissions is \$1,180,000 and the total annual cost is \$563,000. Waste control costs for the mill/refinery tailings pond, including the costs for tailings pond beach dust control and the tailings pond cover, are 88% of the capital cost and 84% of the annual cost.

3.2.4 Wet Mountain Deposit⁽⁵⁾

3.2.4.1 Mine Generated Wastes

The 350 ton/day mine at the Wet Mountain deposit has an underground mine similar to the Lemhi Pass and Hall Mountain mines; so the various generated

(a) See Appendices E and F for detailed capital and annual cost estimates.

wastes and release points are about the same. However, variations in radioactivity and the amount of ^{232}Th released to the environment vary with the amount and grade of the ore put through the mine. As in the other thorite mines, the underground mine operations are assumed to generate 1/4 of the dust while the above-ground operations are assumed to generate 3/4 of the dust. Calculations of the amount of generated wastes and the level of radioactivity in the dust are contained in Appendix C and summarized in Figure 3.7.

The solid waste from the mine is of very low grade and amounts to only about 5.25 ton/day in the form of gangue and wall rock. This waste rock can be used onsite without appreciable harm to the environment.

To control the above-ground dust, water will be used to wet down roads, yards, and storage piles. Wind barriers will also be used to keep the offsite dust level low. The capital cost for this is \$24,000 and the annual cost is \$20,900. A 140,000-cfm ventilation system will be installed in the mine, which will dilute the dust so that no other method of control is needed. The cost of this ventilation system is included in the capital cost for the mine as a whole; so the extra control costs incurred are zero.

The Wet Mountain mine water is assumed to be released at half of the release rate for the Lemhi Pass mine water, i.e., 250 gpm, which is the same as the rate for the Hall Mountain mine. The concentration is assumed to be 12.5 ppm ThO_2 , which is also the same as that of both the Lemhi Pass and Hall Mountain water. Thus, the Wet Mountain mine water is similar to the Hall Mountain mine water in terms of volume and radioactivity. The water control costs are also the same for both mines. The capital cost for a 1-acre settling pond with ditches and pumping equipment is \$21,700 with an annual cost of \$9,700, shown in Table 3.8.

3.2.4.2 Mill/Refinery Generated Wastes

The Wet Mountain mill/refinery processes 0.96% ThO_2 ore from the Wet Mountain mine and produces 99% ThO_2 powder. As in the other thorite mill/refineries, there are three main dust streams to be treated and four liquid streams that are sent to a central tailings pond. The detailed calculations of these streams and their levels are shown in Appendix D and summarized in Figure 3.7.

FIGURE 3.7. Wet Mountain Mine and Mill/Refinery Generated Wastes

TABLE 3.8. Estimated Waste Control Costs for Wet Mountain Mine and Mill/Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	1-acre settling pond, ditches, etc.	21.7	9.7
Underground Mine Dust	140,000-cfm ventilation	0	0
Above-Ground Mine Dust	Spray equipment and wind barriers	24.0	20.9
<u>Mill/Refinery</u>			
Dust From Unloading, Crushing, and Grinding	13,000-cfm cyclone system	11.1	7.8
Drying and Ignition Dust	20,000-cfm wet-impingement scrubber system	38.3	25.0
Packaging Dust	3,500-cfm baghouse filter system	20.3	11.8
Liquid Waste	Tailings pond: 14-acre clay-core dam and reservoir with recycle and distribution systems	902.0	417.0
Tailings Pond Beach Dust	Portable chemical spraying equipment	10.7	14.7
Tailings Pond Cover Radioactivity	1-ft compacted earth cover with 6 in. rock	66.4	9.8
Total Costs		<u>1,094.5</u>	<u>517</u>

(a) Appendices E and F present detailed analyses of the capital and annual costs.

The three streams of airborne wastes have various dust and radioactive release rates. The dust from unloading, crushing, and grinding the ore is assumed to have the same percentage of ^{232}Th (0.85%) as the ore being crushed. This dust is emitted at a rate of 1.6 lb/hr with a radioactive release rate of 6.4×10^{-6} Ci/hr. The 119 lb/hr of airborne wastes released in the drying and ignition processes are mostly water, but the 99% ThO_2 dust emitted is very radioactive on a per unit mass basis; 0.097 lb/hr of ^{232}Th is given off in these processes. This stream has the highest radioactive release rate (9.7×10^{-6} Ci/hr) of the three dust streams in the Wet Mountain mill/refinery. The packaging dust stream is small (0.02 lb/hr), but, because of its higher concentration per lb, it has a radioactive release rate of 1.7×10^{-6} Ci/hr from the packaging process.

The three airborne waste streams are controlled by differing equipment at substantially different costs. A system of fans, hoods, and a 13,000-cfm cyclone dust collector will be used to control the dust from unloading, crushing, and grinding the ore. This system's capital cost is \$11,100 with an annual cost of \$7,800. The drying and ignition stream is the largest and most radioactive of the three dust streams. It will be controlled by a system of fans, hoods, and a 20,000-cfm wet-impingement scrubber with a capital cost of \$38,300 and an annual cost of \$25,000. The control measures for it are the most expensive to purchase, install, and operate. The packaging dust stream is smaller than the other streams but has a higher radioactivity per unit weight. For this reason, a system must be installed to control small dust particles. The system that will be used is a 3500-cfm baghouse filter unit with a capital cost of \$20,300 and an annual cost of \$11,800. All of the solids removed in these dust control units will be recycled back into the mill.

Four liquid waste streams flow into the central tailings pond. As in the previous thorite mill/refineries, most of the ^{232}Th in the tailings pond ($\approx 91\%$) is from the counter-current decantation stream. The amount of radioactivity entering the tailings pond (1.16×10^{-1} Ci/hr) is $\approx 82\%$ of the total radioactivity entering the mill/refinery. This is due, in part, to the

assumption that all of the thorium daughters not released in the dust from unloading, crushing, and grinding the ore are impounded in the tailings pond.

A 14-acre tailings pond with a clay-core dam and an associated piping network will be required to allow the tailings to precipitate out and $\approx 1/4$ of the water to evaporate. The other $\approx 3/4$ of the water will be recycled to the mill after passing through another small settling basin or pond. The clay-core dam in the tailings pond will keep the seepage rate low (0 to 15%). The capital cost for the tailings pond system is \$902,000 and the annual cost is \$417,000. These costs represent $\approx 81\%$ of the total environmental control costs for the Wet Mountain deposit.

To control the beach dust and to keep the radiation level low, the exposed tailings will be sprayed with chemicals. The capital cost of the spray equipment is \$10,700 and the annual cost is \$14,700. As in the other two mill/refineries, a tailings pond cover must be added as part of the decommissioning process. This tailings pond cover will consist of 1 ft of compacted earth and 6 in. of rock, which should prevent radioactive materials from escaping to the atmosphere. The capital cost of this tailings pond cover is \$66,400.

The total capital cost for the environmental control of emissions at the Wet Mountain mine and mill/refinery is \$1,095,000 and the total annual cost is \$517,000, as shown in Table 3.8. The mill/refinery tailings pond is 89% of the capital cost and 85% of the annual cost, including the costs for tailings pond beach dust control and the tailings pond cover.

3.2.5 Palmer, Michigan, Deposit⁽⁷⁾

3.2.5.1 Mine Generated Wastes

The open-pit mine at Palmer, Michigan, produces 10 million tons of ore per yr with an average ThO_2 grade of 0.06%. Of all of the waste streams shown in Figure 3.8, Part A, the dust from the open pit is the most radioactive waste.

The solid waste consists of 3 tons of waste rock for every 10 tons of ore mined.⁽⁸⁾ This rock will be stored onsite; it is of such low radioactivity that there will be no harmful external environmental effects.

FIGURE 3.8. Palmer, Michigan, Mine and Mill Generated Wastes

About 0.125% of the ore mined or 4340 lb/hr is released as airborne wastes.^(a) Because of the mine's open-pit structure, the dust will have to be controlled by careful drilling, blasting, and material-handling procedures. The roads, yards, and storage piles will be wet down by spray equipment to keep the dust levels low. The ore storage piles will have barriers built around them to protect them from the wind. The total capital cost of these dust prevention methods is \$156,000 and the annual cost is \$104,000. The majority ($\approx 62\%$) of the capital cost is for the storage pile wind barriers.

(a) See Appendix C for detailed generated waste calculations.

The mine water is assumed to contain only 1 ppm of ThO_2 , due to the low grade of ore. If 1,500 gpm of mine water are pumped from the mine floor, 0.66 lb of ^{232}Th is removed per hr. The water removed from the mine passes through a 3-acre settling pond. After the solids have settled out in the settling pond, the water is used in the mill circuit as process water. The water can be recycled, after the solids have settled out in the settling pond, because the radioactivity is low, 3.9×10^{-4} Ci/hr. The capital cost for pumping, piping, and settling the mine water is \$236,000 and the annual cost is \$101,000.

The total capital cost of controlling mine wastes from the Palmer, Michigan, mine is \$392,000 and the annual cost is \$205,000, as shown in Table 3.9.

3.2.5.2 Mill Generated Wastes

The Palmer, Michigan, mill processes 0.06% ThO_2 ore from the Palmer, Michigan, mine and produces a 5.2% ThO_2 concentrate. There are two solid waste streams, two dust streams, and one liquid waste stream in the Palmer, Michigan, mill. The detailed calculations of the radioactivity in each of these streams are presented in Appendix D and summarized in Figure 3.8.

The majority ($\approx 99\%$) of the solid waste generated is from the dewatering process while the rest of the solid waste is from the magnetic separation process. To dispose of these wastes, trucks will transport the solids back to the mine where they can be safely disposed of as landfill. The solids content (80%) of this waste stream is high because it has already been dewatered.

There are two airborne waste streams in the mill. The dust stream from unloading, crushing, and grinding the ore is generated at a rate of 327 lb/hr with a radioactive release rate of 1.0×10^{-4} Ci/hr. This dust stream is actually composed of two parts. The first is from the primary crusher, which processes ore 240 days/yr at a rate of 1895 ton/hr. The crushed ore is then stored and processed through the rest of the mill at a rate of 1377 ton/hr for 330 days/yr. After being stored, the ore is crushed again and ground, which also contributes to the previously mentioned 327 lb/hr of dust. This figure represents the maximum dust emission value that would be released during all

TABLE 3.9. Estimated Waste Control Costs for Palmer, Michigan,
Mine, Mill, and Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	3-acre settling pond, piping and pumps to mill and surface waters	236.0	101.0
Mine Dust	Spray equipment and ore storage wind barriers	156.0	104.0
<u>Mill</u>			
Dust from Unloading, Crushing, and Grinding	Four 50,000-cfm cyclone systems	139.0	87.7
Dust from Drying, Magnetic Separating, and Loading	60,000-cfm wet- impingement scrubber system	108.0	66.7
Liquid Waste	200-acre clay-lined tailings pond with recycle and distribu- tion system to mill	7,222.0	2,290.0
<u>Refinery</u>			
Dust from Unloading and Grinding	10,000-cfm baghouse filter system	49.5	23.9
Drying and Ignition Dust	16,000-cfm low-energy venturi scrubber system	36.9	25.1
Packaging Dust	3,000-cfm baghouse filter system	17.8	7.7
By-Product Recovery Dust	24,000-cfm wet- impingement scrubber system	44.7	26.9
Liquid Wastes	20-acre tailings pond with recycle and distribu- tion systems	993.0	423.0
Tailings Pond Beach Dust	Portable chemical spraying equipment	6.5	5.8
Tailings Pond Radioactivity	6-ft compacted earth cover with 6 in. rock	254.0	2.5
Total Costs		<u>9,260</u>	<u>3,170</u>

(a) Appendices E and F present detailed analyses of the capital and annual costs.

of the time that the mill is operating. The percentage of ^{232}Th in the dust is of the same as that in the ore being crushed and ground (0.053). The dust from drying, magnetic separating, and loading is released at a rate of 2.5 ton/hr of which 0.1 lb/hr is ^{232}Th . The radioactive release rate for this dust stream is 6.0×10^{-5} Ci/hr from all radioactive sources.

The airborne wastes are controlled by individual systems. To control the dust from unloading, crushing, and grinding, a 200,000-cfm cyclone system will be installed to collect the dust. Half of this cyclone system will be used on the primary crusher and will be shut down when it is not in use. The capital cost for these control systems is \$139,000 and the annual cost is \$87,700. The dust from drying, magnetic separating, and loading will be controlled by a 60,000-cfm wet-impingement scrubber system. The capital cost of this system is \$108,000 and the annual cost is \$66,700. All of the dust collected by the above systems will be periodically recycled from the dust collectors back into the main process stream.

The final waste stream is the liquid discharged from the dewatering process. This stream has a flow rate of 3100 gpm and a radioactive release rate of 3.6×10^{-2} Ci/hr, which is higher than the two dust streams. The liquid wastes are piped to a tailings pond where the solids are allowed to precipitate. From this 200-acre pond, $\approx 3/4$ of the water is recycled to the mill for use as process water and the rest is allowed to evaporate or, if permissible, drain into the natural surface water.

The 200-acre tailings pond will have a clay core and a clay liner to keep seepage low (0 to 3%) and a distribution system to spread the solids evenly throughout the pond. The total capital cost of the tailings pond, including the recycle system, is \$7,220,000 and the annual cost is \$2,290,000.

The total capital cost for the Palmer, Michigan, mill is \$7,470,000 and the total annual cost is \$2,440,000, as shown in Table 3.9. The tailings pond and recycle system costs are $\approx 97\%$ of the total capital cost and $\approx 94\%$ of the total annual cost.

3.2.5.3 Refinery Generated Wastes

The Palmer, Michigan, refinery processes the 5.2% ThO₂ concentrate from the Palmer, Michigan, mill and produces a 99% ThO₂ powder. The detailed flowsheet and calculations of the radioactive wastes are presented in Appendix D and summarized in Figure 3.9. There are four dust streams that need to be controlled and five liquid streams that empty into the central tailings pond.

The four dust streams vary in size and contain different amounts of radioactivity. The dust from unloading and grinding the concentrate is emitted at a rate of 0.95 lb/hr and has a radioactive release rate of 2.6×10^{-5} Ci/hr. The percentage ²³²Th in the dust stream is the same as that in the entering concentrate. The amount of dust from the ignition and drying process is quite small, although the stream has a release rate of 1200 lb/hr consisting mainly of steam. Only 0.8 lb/hr of ²³²Th is released in this stream, which has a radioactive release rate from all radioactive sources of 8.0×10^5 Ci/hr. The packaging dust stream has a waste release rate of only 0.16 lb/hr but, since the ²³²Th concentration is high ($\approx 87\%$), the radioactive release rate (1.4×10^{-5} Ci/hr) is high on a per unit weight basis. The by-product dust is emitted in a 3.2 ton/hr stream, but most of this stream, like the ignition and drying dust stream mentioned previously, is water. Although this is the largest stream emitted, it has the lowest radioactive release rate (3.7×10^{-6} Ci/hr). The amount of ²³²Th is quite low in this stream (0.0062 lb/hr). The majority of the radioactivity is from the uranium and its daughter products that are being recovered as by-products.

A separate system will be used to control each of the four dust streams. To control the unloading and grinding dust, a system composed of fans, hoods, and a 10,000-cfm baghouse filter unit will be installed. The capital cost of this system is \$49,500 and the annual cost is \$23,900. The ignition and drying dust will be controlled by a 16,000-cfm low-energy venturi scrubber system. The capital cost of this is \$36,900 and the annual cost is \$25,100. The packaging dust stream, though small, needs to be tightly controlled because of its

FIGURE 3.9. Palmer, Michigan, Refinery Effluents

high radioactivity per unit weight. A 3,000-cfm baghouse filter unit will be used to control this stream with a capital cost of \$17,800 and an annual cost of \$7,700. Finally, the by-product recovery dust stream--the largest dust stream will--need a 24,000-cfm wet-impingement scrubber to control its dust. The capital cost of this system is \$44,700 and the annual cost is \$26,900.

The five filtration liquid streams all flow into the central tailings pond. The first filtration stream contains $\approx 94\%$ of the ^{232}Th entering the pond. It flows into the pond at a rate of 817 gpm. The radioactive release rate of 4.4×10^{-1} Ci/hr is the most radioactive of any stream, including the two product streams, leaving the refinery. The tailings pond retains $\approx 84\%$ of the entering radioactivity. The reason for this large amount of radioactivity, compared to the other waste streams, is that most of the daughter products of thorium and uranium accumulate in the pond, as well as considerable amounts of uranium and thorium.

The proposed pond will cover 20 acres and will have a 3-ft clay core to keep the seepage rate low. The tailings pond system will also include a recycle system for $\approx 3/4$ of the water. The total capital cost of the tailings pond and the associated recycle system is \$993,000 and the annual cost is \$423,000. At this tailings pond like the others, beach dust will have to be kept tied down so that the dry tailings do not enter the atmosphere. The capital cost of the equipment for beach dust control is \$6,500 and the annual cost is \$5,800. To decommission the tailings pond after the refinery is closed, a cover of 6 ft of earth and 6 in. of rock will be placed over the pond. This should prevent any radioactive material from spreading to the external environment. The capital cost of the tailings pond cover (\$254,000) is not incurred until after the refinery shuts down. A sinking fund with an annual cost of \$2500 would be established to pay for the cover.

The total capital cost of environmental control technology for the Palmer, Michigan, refinery is \$1,400,000 and the total annual cost is \$515,000, as shown in Table 3.9. The tailings pond, with the pond cover and beach dust control, makes up $\approx 89\%$ of the capital cost and $\approx 84\%$ of the annual cost of the refinery control equipment. The capital cost of the mill's environmental

control methods amounts to $\approx 81\%$ of the total capital cost of \$9,260,000 while the mill's projected annual costs are $\approx 77\%$ of the Palmer, Michigan, deposit's total annual cost of \$3,170,000.

3.2.6 Bald Mountain Deposit⁽⁷⁾

3.2.6.1 Mine Generated Wastes

The open-pit mine at Bald Mountain, Wyoming, will produce 10,000 tons of ore per day with an average ThO_2 grade of 0.00951%. It will have two types of wastes generated at the mine site: dust and water, as shown in Figure 3.10.

At Bald Mountain like the Palmer, Michigan, mine, there are 3 tons of waste rock for every 10 tons of ore mined; so 125 ton/hr of waste rock are removed from the mine. It was assumed that little radiation is associated with this waste rock and that there will be no harmful effects from storing the rock onsite.

About 0.125% of the ore mined or 1040 lb/hr will potentially be released as dust.^(a) At the Bald Mountain mine like the Palmer, Michigan, open-pit mine, the dust cannot be completely controlled. To keep the dust levels low, the roads, yards, and storage piles will be wet down by spray equipment and the ore storage piles will be sheltered from the wind. The total capital cost for dust control at the mine is \$94,000 and the annual cost is \$71,300. Most of the capital costs (50.2%) are for the wind barriers. All of the costs are shown in Table 3.10.

The mine water was assumed to contain 1 ppm ThO_2 in equilibrium with both its daughter products and ^{238}U and ^{235}U . The flow rate was assumed to be 1000 gpm, which is less than at Palmer, Michigan, because the mine is smaller and there is less precipitation. The total radioactive release rate for the mine water is 2.6×10^{-4} Ci/hr.^(a) Since this rate is not very high, a 2-acre settling pond that will allow the solids to settle out is the only treatment method needed. The water can then be used in the mill or released to the local surface water. The capital cost for the settling pond, pipes, and pumps is \$175,000 and the annual cost is \$78,300.

(a) Refer to Appendix C for detailed calculations.

FIGURE 3.10 Bald Mountain Mine and Mill Effluents

TABLE 3.10. Estimated Waste Control Costs for Bald Mountain Mine, Mill, and Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	2-acre settling pond, piping and pumps to mill and surface waters	174.7	78.3
Mine Dust	Spray equipment and ore storage wind barriers	94.4	71.3
<u>Mill</u>			
Dust from Unloading, Crushing, and Grinding	50,000-cfm cyclone system	34.7	26.7
Dust from Drying, Magnetic Separating, and Loading	30,000-cfm wet-impingement scrubber system	54.0	35.0
Liquid Waste s	40-acre clay-lined tailings pond with recycle and distribution systems	2,350.0	795.0
<u>Refinery</u>			
Unloading and Grinding Dust	10,000-cfm cyclone system	8.8	6.1
Drying and Ignition Dust	6,000-cfm low-energy venturi system	16.0	10.0
Packaging Dust	1,200-cfm baghouse filter system	8.2	4.2
By-Product Recovery Dust	15,000-cfm wet-impingement scrubber system	30.0	18.7
Liquid Waste	6-acre pond clay-lined tailings pond with no recycle system	209.0	62.1
Tailings Pond Beach Dust	Portable chemical spraying equipment	4.0	2.6
Tailings Pond Radioactivity	6-ft compacted earth cover with 6 in. rock	96.9	4.8
Total Costs		<u>3,080</u>	<u>1,110</u>

(a) Detailed calculations of the capital and annual costs are shown in Appendices E and F.

The total capital cost for the mine environmental control methods and equipment at Bald Mountain is \$269,000 and the annual cost is \$150,000, as shown in Table 3.10.

3.2.6.2 Mill Generated Wastes

The Bald Mountain mill processes the 0.00951% ThO_2 ore from the Bald Mountain mine and produces a 5.7% ThO_2 concentrate. At the Bald Mountain mill like the one at Palmer, Michigan, there are two solid waste streams, two dust streams, and one liquid waste stream. The detailed calculations of the radioactivity of each of these streams are presented in Appendix D and summarized in Figure 3.10.

There are 375 ton/hr of solids returned to the mine from two areas of the mill: the dewatering process and the magnetic separators. Most (99%) of the ore is from the dewatering process. The waste, which is $\approx 80\%$ solid, will be trucked back to the mine and used as landfill.

The airborne wastes originate in three areas and combine into two streams. As in the Palmer, Michigan, mill, the dust stream from crushing and grinding the ore is composed of two parts. The first part is from the primary crusher, which emits 45.5 lb/hr and operates 240 days/yr. The second part is from the secondary crusher and grinders, which emit dust at a rate of 33 lb/hr and operate 330 days/yr. These two dust streams will be combined and treated together. The combined radioactive release rate is 3.9×10^{-6} Ci/hr. This rate is the maximum value emitted when both the primary and secondary crushers are operating, which is $\approx 2/3$ of the time. The percentage of ^{232}Th in this dust is the same as that in the ore being crushed. The dust from drying, magnetic separating, and loading, which has a radioactive release rate of 2.0×10^{-6} Ci/hr, from all sources is released at a rate of 174 lb/hr, of which of 3.4×10^{-3} lb/hr is ^{232}Th .

Two systems will be used to control the airborne waste streams. One cyclone dust collector will be used on the stream from unloading, crushing, and grinding the ore. This system will operate at 50,000 cfm and will be used for both the primary crushing operation and the secondary crushing and grinding operation. The capital cost of this system is \$34,700 and the annual cost

is \$26,700. The dust from drying, magnetic separating, and loading will be collected by a 30,000-cfm wet-impingement scrubber system. The capital cost of this system is \$54,000 and the annual cost is \$35,000. As in the Palmer, Michigan, mill, all of the dust collected in the above systems will be periodically recycled back into the main process stream.

The liquid waste from the dewatering process is the largest and most radioactive waste stream in the mill. The liquid wastes flow into a tailings pond at a rate of 867 gpm with a radioactive release rate of 1.3×10^{-3} Ci/hr. A 40-acre clay-lined settling pond will be used to allow the solids to precipitate. Approximately 3/4 of the liquid will be recycled and used as process water in the mill; the rest of the water will be allowed to evaporate or drain into the surface water. The clay lining of the pond should keep the seepage rate low (0 to 3%). A distribution system will be used to spread the solids evenly on the pond bottom. The total capital cost of the tailings pond, including the recycle system for the liquids and the distribution system for the solids, is \$2,350,000 and the annual cost is \$795,000.

The total capital cost of the environmental control techniques and equipment for the Bald Mountain mill is \$2,440,000 and the total annual cost is \$856,000, as shown in Table 3.10. The tailings pond and associated systems make up $\approx 96\%$ of the capital cost and $\approx 93\%$ of the annual cost of the Bald Mountain mill's environmental control expenses.

3.2.6.3 Refinery Generated Wastes

The Bald Mountain refinery processes the 5.7% ThO_2 concentrate from the Bald Mountain mill and produces a 99% ThO_2 powder. The detailed flowsheet and waste radioactivity calculations are presented in Appendix D and summarized in Figure 3.11. There are four dust streams that need to be controlled and five liquid streams that empty into the central tailings pond.

The airborne wastes are divided into four dust streams. The dust from unloading and grinding the concentrate is released at the rate of 0.03 lb/hr with a radioactive release rate of 8.9×10^{-7} Ci/hr. The percentage of ^{232}Th in the dust is the same as that in the concentrate being unloaded and ground.

FIGURE 3.11 Bald Mountain Refinery Generated Wastes

Only 3.0×10^{-2} lb/hr of ^{232}Th is released in the ignition and drying process, even though the waste stream flow rate is 40 lb/hr with a radioactive release rate of 3.0×10^{-6} Ci/hr. Most of the mass is water released in the process. The packaging dust is emitted at the rate of 6.2×10^{-3} lb/hr, which is low, but the radioactive release rate is 5.4×10^{-7} Ci/hr, which is high on a per unit weight basis. The release rate is high because the dust being released is 99% ^{232}Th , the same as the product being packaged. The by-product dust is emitted at the rate of 164 lb/hr. Most of this stream is water emitted when the by-product is dried. The amount of ^{232}Th emitted is 2.3×10^{-4} lb/hr. The total radioactive release rate of 1.4×10^{-7} Ci/hr makes this the least radioactive stream in the refinery.

Each of the four airborne waste streams has a separate control system. A 10,000-cfm cyclone system will be used to control the dust from unloading and grinding the concentrate. The capital cost of this system is \$8,800 with an annual cost of \$6,100. A 6,000-cfm low-energy venturi scrubber system will be used to control the ignition and drying dust. The capital cost of this system is \$16,000 and the annual cost is \$10,000. The packaging dust stream, though small, needs to be closely controlled because its dust is 99% ThO_2 . A 1,200-cfm baghouse filter unit will be used to control this stream at a capital cost of \$8,200 and an annual cost of \$4,200. The largest dust stream, the by-product recovery dust, will be controlled by a 15,000-cfm wet-impingement scrubber. The capital cost of this system is \$30,000 with an annual cost of \$18,700. As before, all of the dust collected will be recycled back into the main process stream.

The five filtration liquid streams all flow into the central tailings pond. The first filtration stream contains $\approx 93\%$ of the ^{232}Th entering the pond and flows into the pond at a rate of 4 gpm. The radioactive release rate of the combined streams is 1.6×10^{-2} Ci/hr and is the largest of any waste stream from the refining process, including the product and by-product streams. The tailings pond retains 82% of the entering radioactivity. The pond's high radioactivity may be explained by the fact that most of the thorium and uranium daughter products, as well as considerable amounts of thorium and uranium, end up in the tailings pond.

The proposed tailings pond is 6 acres in size with a 3-ft clay liner to keep the seepage low (0 to 3%). This tailings pond, unlike the Palmer, Michigan, tailings pond, has no recycle system because all of the liquid should evaporate. The total capital cost of the tailings pond at the Bald Mountain refinery is \$209,000 while the annual cost is \$62,100.

Like the other tailings ponds, the beach dust here must be controlled to minimize the release of dust via the wind. The capital cost of the equipment to keep the beach dust tied down is \$4,000 while the annual cost is \$2,600. After the refinery operation ends, the tailings pond will be covered with 6 ft of earth and 6 in. of rock to contain the radioactive tailings. The capital cost of this tailings pond cover is \$96,900.

The total capital cost for the Bald Mountain refinery's environmental control techniques and equipment is \$373,000 while the annual cost is \$109,000, as shown in Table 3.10. The capital cost for the tailings pond, including beach dust control and pond cover, is $\approx 57\%$ of the annual cost of controlling the radioactive wastes. For the Bald Mountain deposit, the capital cost of the mill's environmental control methods amount to $\approx 79\%$ of the total capital cost of \$3,080,000 and the mill's annual costs are $\approx 76\%$ of the total annual cost of \$1,110,000.

3.2.7 Conway Granite Deposit(2,3,4,9)

3.2.7.1 Mine Generated Wastes

The open-pit mine at the Conway Granite site in New Hampshire produces 100,000 tons of ore per day with an average ThO_2 grade of 0.006%. As shown in Figure 3.12, there are two radioactive waste streams leaving the mine: one airborne stream and one water stream.

There will be 2-tons of waste rock for every 10 tons of ore mined. The waste rock will be stored onsite, either in the mine or adjacent to it. It will cause no external environmental effects because the radioactivity is quite low.

A. MINE

2000 gpm H₂O
(9.2×10^{-4} ci/hr)

DUST 10,400 lb/hr
(5.7×10^{-4} ci/hr)

SOLIDS 833 ton/hr

ORE
417 ton/hr

B. MILL

ORE

4545 ton/hr
(5.0×10^{-1} ci/hr)

100,000 cfm
DUST 454 lb/hr
(3.4×10^{-6} ci/hr)

SOLIDS TO MINE 5300 ton/hr
(1.6×10^{-1} ci/hr)

270 gpm
H₂O TO TAILINGS POND
67 ton/hr
(2.3×10^{-2} ci/hr)

30,000 cfm
DUST 0.029 lb/hr
(1.8×10^{-5} ci/hr)

PRODUCT (57 % ThO₂)
574 lb/hr
(3.1×10^{-1} ci/hr)

FIGURE 3.12. Conway Granite Mine and Mill Generated Wastes

The airborne waste stream consists of 10,400 lb/hr of dust released in the mining operations if $\approx 0.125\%$ of the ore mined is dust. This stream has a radioactive release rate of 5.7×10^{-4} Ci/hr. Due to the open structure of the mine, the dust will have to be controlled by careful mining methods, wetting down the mining and transportation areas, and placing wind barriers around the ore storage piles. The capital cost of these various methods is \$225,000 and the annual cost is \$169,000. The majority ($\approx 67\%$) of the capital cost is for the ore storage pile wind barriers.

Because of the low grade of the ore mined, the mine water is assumed to contain only 1 ppm of ThO_2 . In the water, 0.88 lb/hr of ^{232}Th is removed per hr from the mine assuming a flow rate of 2000 gpm. The radioactivity level is 9.2×10^{-4} Ci/hr, low enough for the water to be re-used in the mill after the solids are allowed to precipitate in a 4-acre settling pond. The excess water not needed in the mill may be discharged to surface waters. The capital cost for pumps, pipes, and the pond are \$293,000 while the annual cost is \$153,000.

The total capital cost of controlling the mine wastes from the Conway Granite Mine is \$518,000 with a total annual mine control cost of \$322,300 as shown in Table 3.11.

3.2.7.2 Mill Generated Wastes

The Conway Granite mill processes 0.006% ThO_2 ore from the Conway Granite mine and produces a 57% ThO_2 concentrate. One solid stream, two dust streams, and one liquid stream come from the mill. The detailed calculations of the radioactive release rates of all of these streams are presented in Appendix D and summarized in Figure 3.12.

A large amount of solids are to be returned to the mine after being dewatered. Lime may be added to the waste stream to neutralize it so that it can be disposed of safely at the mine site. The solid waste that is to be disposed of in the mine contains 1.6×10^{-1} Ci/hr of radioactivity.

The dust stream from crushing and grinding the ore is generated at a rate of 454 lb/hr with a radioactive release rate of 3.4×10^{-6} Ci/hr. The dust is assumed to have the same percentage of ^{232}Th as the ore being crushed.

TABLE 3.11. Estimated Waste Control Costs for Conway Granite Mine, Mill, and Refinery^(a)

<u>Generated Wastes</u>	<u>Type of Control</u>	<u>Capital Cost (\$1000)</u>	<u>Annual Cost (\$1000)</u>
<u>Mine</u>			
Mine Water	4-acre settling pond, piping and pumps to mill and surface waters	293.0	153.0
Mine Dust	Spray equipment and ore storage wind barriers	225.0	169.0
<u>Mill</u>			
Dust from Unloading, Crushing, and Grinding	two 50,000-cfm cyclone systems	69.5	53.0
Drying and Packaging Dust	30,000-cfm wet- impingement scrubber system	54.0	34.9
Liquid Wastes	20-acre clay-lined tailings pond with recycle and distribution systems	908.0	368.0
<u>Refinery</u>			
Waste Sludge	2.5-acre clay-lined land- fill pit with trucks and hoppers	179.0	65.5
Drying and Packaging Dust	12,000-cfm baghouse filter and HEPA filter system with demister	187.0	90.6
Liquid Waste	10-acre clay-lined tailings pond with no recycle system	327.0	86.0
Tailings Pond Beach Dust	Portable chemical spraying equipment system	4.0	3.1
Tailings Pond Radioactivity	6-ft compacted earth cover with 6 in. rock	146.0	1.4
Total Costs		<u>2,390</u>	<u>1,025</u>

(a) Detailed calculations of the capital and annual costs are shown in Appendices E and F.

The second dust stream, the dust from drying and packaging the ore, is a much smaller (0.029 lb/hr) but more radioactive stream (1.8×10^{-5} Ci/hr). The higher radioactivity is due to the assumption that the percentage of ThO_2 in the dust is the same as that in the concentrate being packaged.

Two control systems will be used to control the airborne waste streams. A system of two 50,000-cfm cyclone dust collectors will be used to control the dust from unloading, crushing, and grinding the ore. The capital cost of this system is \$69,500 while the annual cost is \$53,000. A system using a 30,000-cfm wet-impingement scrubber will be needed to control the dust from drying and packaging. The capital cost of this system is \$54,000 and the annual cost is \$34,900. All of the solids collected in the above dust control systems will be recycled back into the main mill process streams.

Liquid waste flows into the tailings pond from the precipitation and filtration process. The flow rate is 270 gpm with radioactive release rate of 2.3×10^{-2} Ci/hr. A 20-acre clay-lined pond will be used to handle this waste. Most of the liquid stream ($\approx 3/4$) will be returned to the mill for use as process water after the solids have settled out. An auxiliary settling pond will also be needed. Before the liquid is used in the mill, it will flow through the auxiliary pond to ensure that all the solids have settled out. The auxiliary pond will not need a pond cover when it is decommissioned because the radioactivity level is low. The clay-lining of the pond should minimize seepage (0 to 3%). The recycle and distribution systems will handle most of the liquids. The capital cost of the tailings pond system is \$908,000 with an annual cost of \$368,000.

The total capital cost for environmental control of emissions at the Conway Granite mill is \$1,030,000 while the annual cost is \$456,000. The mill tailings pond system makes up $\approx 88\%$ of the capital cost and $\approx 81\%$ of the annual cost of controls, as shown in Table 3.11.

3.2.7.3 Refinery Generated Wastes

The Conway Granite refinery processes 57% ThO_2 concentrate and produces a 99% ThO_2 product. This refinery is similar to the stockpile refinery except that a uranium recovery system is added. There are nine waste streams:

one solid, one dust, and seven liquid streams. The radioactivity in each of these streams is calculated in Appendix D and summarized in Figure 3.13.

The waste sludge stream leaving the refinery is 80% solids and has a radioactive release rate of 6.8×10^{-3} Ci/hr. This stream is emitted from the refinery at a rate of 660 lb/hr. Because of its radioactivity, this sludge must be buried at an approved landsite. The sludge will be trucked in hoppers to a 2.5-acre clay-lined pit. This method of disposal will be less costly than a conveyer system or slurry line. The capital cost of the sludge pit, the trucks, and the hoppers is \$179,000 and the annual cost is \$65,500.

FIGURE 3.13. Conway Granite Refinery Generated Wastes

The smallest and least radioactive waste stream is the dust stream from drying and loading the concentrate. Most of the 313 lb/hr of dust given off are water and carbon dioxide from the drying process; however, of this only 5.6 lb/hr of ^{232}Th are emitted. The 5.7×10^{-4} Ci/hr radioactivity level is not as large as the levels in other streams in the refinery but, because the dust is 99% ThO_2 , the stream must be closely controlled.

A 12,000-cfm baghouse filter system with a HEPA filter attached must be installed to control the drying and packaging dust. Because of the amount of water present in the stream being treated, a 1,200-cfm air demister must be installed for the system to operate correctly. The capital cost of the entire system is \$62,300 and the annual cost is \$90,600.

The seven liquid streams that flow into the tailings pond are more radioactive than the amount of ^{232}Th would indicate. Most of ^{232}Th , ^{238}U , and ^{235}U daughter products empty into this pond. The 2.6×10^{-1} Ci/hr radioactive release rate is 82% that of the concentrate being processed. The liquid stream from the plate-and-frame press process has $\approx 80\%$ of the ^{232}Th entering the pond in it, but, as previously mentioned, it is the daughter products that cause the pond to be highly radioactive. The total flow into the pond is 20 gpm.

The refinery tailings pond will be a 10-acre clay-lined pond without a recycle system. The water is too radioactive for it to be used as process water in the refinery. The capital cost of this tailings pond is \$327,000 while the annual cost is \$86,000. As with the other tailings ponds, the beach dust must be kept tied down with chemicals. The capital cost of the spray equipment is \$4,000 and the annual cost is \$3,100. When the refinery ceases operation, the pond must be covered with 6 ft of earth and 6 in. of rock. The capital cost of this pond cover is \$146,000.

The total capital cost for controls at the Conway Granite refinery is \$842,000 and the annual cost is \$247,000. The tailings pond capital cost, including beach dust control and tailings pond cover, is $\approx 57\%$ of the capital

cost and $\approx 37\%$ of the annual cost for control of the generated wastes at the refinery. The capital cost for waste control from all phases of ThO_2 powder production at the Conway Granite deposit is \$2,390,000 and the annual cost is \$1,025,000, as shown in Table 3.11.

3.3 REFERENCES

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4.0 ASSESSMENT OF AVAILABLE ENVIRONMENTAL CONTROL TECHNOLOGIES

The environmental control technologies available to protect the offsite environment from thorium mining, milling, and refining effluents were reviewed in the literature and through discussions with suppliers of commercial environmental control equipment. There are many methods available to control the wastes. The selection of the best methods to use will depend upon the processes employed and site-specific data. The equipment and facilities selected for environmental control will be determined during the detailed feasibility and environmental impact studies for the specific site.

The typical types of wastes that must be controlled during the mining, milling, and refining of thorium are shown in Figure 4.1. The tailings pile, which contains the bulk of the radioactivity, will be a major source of concern for offsite release of effluents during operations and after operations are terminated.

FIGURE 4.1. Typical Types of Wastes from Mining, Milling, and Refining Thorium

Data from the uranium industry were used for most of the analysis because little information was available about environmental controls for the thorium industry. Some of the general differences between thorium and uranium are outlined in Table 4.1. Because site-specific data were lacking, all of these differences could not be factored into this study.

The thorium industry, like the uranium industry, would be associated with a wide range of processes, chemicals, by-products, locations, geologies, etc. The environmental control methods used at one site may not be suitable at another site. The various methods of controlling wastes are listed in Figure 4.1 and discussed in the following subsections.

The wastes can be controlled to different levels by methods that are in various stages of advancement. The effectiveness and costs of some of the methods are addressed in Section 5 of the report. The effectiveness and costs of the methods are site and ore specific.

4.1 METHODS OF ENVIRONMENTAL CONTROL FOR MINING

The thorium is mined in both underground and surface mines. The generated wastes with the largest chance of offsite release from the mine are:

- untreated mine water that can reach underground aquifers or surface waters;
- ore dust generated from drilling, blasting, and materials handling operations, and dust generated by the wind and vehicles from roads, yards, and ore storage piles;
- thoron (radon) gas released from the ore during mining, handling, and storage;
- fumes generated by the equipment (e.g., diesel engines).

The underground mine dust, the thoron released, and the fumes generated by equipment are more controllable because the mine ventilation is used to collect and channel the wastes. The methods of controlling mine water and wastes outside the underground area are similar for both types of mines. The biggest problem at the mine is the control of radon gas. In an underground

TABLE 4.1. General Differences Between Thorium and Uranium Ores
in Mining, Milling, and Refining

Thorium Ore	Uranium Ore
1. Contained in igneous rock	1. Contained in sedimentary rock (sandstone)
2. Form: nodules peppered in a rock matrix	2. Form: fines coating sand kernels
3. High degree of grinding needed for feed material	3. Moderate crushing and grinding needed for feed material
4. High silica	4. Low silica
5. Gravity separations difficult	5. Gravity separations easier
6. High slime content in mill tailings effluent	6. High sand content in mill tailings effluent
7. Mineralogy, climatology, and topography are different than current uranium mines	7. Current mines mostly in arid regions
8. High pyrite and sulfides can affect mine water pH	8. pH usually about 7 (neutral)
9. Behavior of thoron (radon-220) not well established	9. Radon-222 is better understood
10. Radium-228 and radium-224 daughters have short half-lives (6.7 years and 3.69 days) and require short-term control and containment.	10. Thorium-230 and radium-226 daughters have long half-lives (1622 years and 75,200 years) and require long-term control and containment.
11. Thoron (radon-220) has a short half-life (54.5 seconds). Requires less time to filter and less cover to contain.	11. Radon-222 has a longer half-life (3.825 days). Requires more time to filter and greater cover to contain.
12. Probably a greater hazard to miners	12. Probably not as great a hazard to miners

mine, it is feasible to control thoron wastes but releases in open-pit mines are essentially impossible to control.

4.1.1 Mine Water Control

Standard mining practices will be used to channel the mine water in a way that will minimize the pollution due to erosion. Water treatment may be required in some cases where the turbidity, dissolved radioactive material content, acidity, or heavy metals content are high. In some thorium mines, the acidity may be higher than in uranium mines because of the ore's higher pyrite and sulfide content. The mine water can be utilized in milling and refining operations when they are located nearby and can also be used to control the release of dust from onsite roads, ore piles, materials handling, and drilling and blasting operations.

The mine water will usually be collected and possibly treated in a settling pond prior to subsequent use or discharge into natural surface waters or drainage systems. Flocculation and clarification⁽¹⁾ can be employed, when needed, to reduce the total solids in solution, the chemical oxygen demand, and the radium. Flocculants are water-soluble organic polyelectrolytes that are sometimes used with inorganic coagulants and/or coagulant aids to agglomerate solids suspended in aqueous systems. The flocculation process collects colloidal particles into larger and more dense aggregates, which then settle more rapidly and more completely in the clarification step. The choice of the specific chemicals used in the process depends upon the characteristics of the waste.

Ion exchange⁽¹⁾ can be used to collect the thorium and uranium. It also has been used to collect radium but not much is known about the process. The exchange of ions by means of a synthetic resin is a proven method of reducing the dissolved solids contained in water. Uranium has been successfully extracted from mine water and mill ore leach pulp; the technology should also be adaptable to recovering thorium.

Barium salt coprecipitation can be used in the pond to precipitate the radium out of the liquid streams. In the past, the common salts used along with a flocculant for coprecipitation of radium were BaSO_4 , Ba CO_3 , and

BaCl_2 . The relative effectiveness of barium salts is shown in Table 4.2.⁽²⁾ Barium chloride has been the most effective and its product is relatively insoluble.

Lime precipitation^(1,2) can be used in the settling pond. The lime will help precipitate out the heavy metals and increase the pH. Neutralization with lime also tends to remove radium from the waste stream (up to 90% in highly acidic solutions).

In the unlikely event that mine water cannot be treated to meet environmental discharge requirements, it will be necessary to collect and evaporate the water with an evaporator or in a pond. The solids collected could be buried after operations cease by either covering the pond or moving them to the mill tailings pond or an approved landfill.

TABLE 4.2. Radium Decontamination Using Barium Salts^(a)

Effluent pH	Reagent	Reagent Addition g/l	Radium Concentration Cix10 ⁻⁵ /ml		Radium Removal %
			Before Treatment	After Treatment	
Neutral	BaSO ₄	0.3	10	3	70
		1.0	30	7	77
	BaCO ₃	0.1	47	3	94
		0.2	49	4	92
	BaCl ₂	0.03	80	2	97
		0.06	44	0.6	99
		0.1	40	0.2	99
		0.2	43	0.2	99
	Acidic	BaCO ₃	0.1	15 ^(b)	1.8 ^(c)
0.2			15 ^(b)	2.0 ^(c)	87 ^(c)
0.3			15 ^(b)	3.0 ^(c)	80 ^(c)
BaCl ₂		0.1	15 ^(b)	0.5 to 1.5	90 to 97

(a) Mill-scale tests, Union Carbide Corporation, Uravan, Colorado.

(b) Average several sampling periods; individual samples erratic.

(c) Differences in results not considered significant.

Some mines on the other hand, unlike the ones we studied, may be quite dry. Some uranium mines are very dry; so water must be transported to the site for drilling and blasting operations.

4.1.2 Ore Dust (Controlled and Uncontrolled)

4.1.2.1 Controlled Ore Dust

The dust generated in the underground mine can be categorized as controlled dust. The underground mine's ventilation system helps to control dust at safe working levels for the workers. Auxiliary exhausts can be used where drilling, blasting, and materials handling generate larger quantities of dust. Water is used to reduce the dust from drilling. Blankets and water spray curtains can also be used to tie down the dust from blasting and materials handling. The use of the latest equipment and the best standard operating procedures will help control the dust.

The dust carries with it thorium, radium, and other alpha and beta emitters.⁽³⁾ The contamination levels at any place and time depend on the ore grade, the type of operations involved, moisture, ventilation, and other such factors. Generally, where low-grade ore is mined and ventilation is good, the contamination levels in uranium mines are well within the prescribed levels. Mines that produce high-grade ore have been known to have substantially higher levels of contamination. Underground contamination in thorium mines is expected to be more of a problem because the short half-life of thoron (54.5 seconds) will result in a greater accumulation of daughter products in the mine rooms, shafts, ventilation ducts, etc. Usually thorium mines will contain more silica than uranium mines; so the protection of workers from silicosis will be an added concern.

The dust collected and discharged through the underground mine ventilation system can be passed through dust collection equipment if it is deemed necessary. The types of dust collection equipment that could be used are discussed in Section 4.2.1.

4.1.2.2 Uncontrolled Ore Dust

In a surface mine, the ore dust generated by the drilling, blasting, and handling operations is not as major a concern as it is underground. Use of the best equipment and best procedures will minimize the amount of dust generated.

Dust suppression is necessary for both surface and underground mines in these surface areas:

- roads
- yards
- ore stockpiles
- mine loading and mill unloading areas.

The roads and yard dust can be minimized by periodically spraying surfaces with water and chemicals. The ore stockpiles can be protected from the prevailing winds by erecting wind barriers⁽⁴⁾ and, if necessary, by periodically wetting them or encrusting them with chemicals. The loading and unloading areas can also be protected from the wind, and spray curtains can be used if necessary.

4.1.3 Thoron (Radon-220) Gas Control

In open-pit mines, there is little that can be done to control the release of thoron to the environment. The thoron is continually diluted in the air and does not build up or accumulate like it could in unventilated areas of underground mines; however, it is necessary to monitor radon in surface mines during periods of air stagnation, thermal inversions, etc. Most of the concern is about the thoron daughters because they present a hazard to the workers' health when inhaled. Underground mines must rely on ventilation systems to prevent the accumulation of thoron and its daughter products in the mine. The ventilation systems also dilute the concentration of these products with air to meet effluent discharge requirements for the mine.

The behavior of thoron, compared to radon in uranium mines, is not well understood. The physical properties of radon and thoron are the same except for the half-life variation of 3.82 days and 54.5 seconds, respectively. In underground uranium mines,⁽³⁾ the ambient concentration of radon is a function

of barometric pressure variations, rock porosity, the volume of the water seepage, the volume of ventilation, and, to a surprisingly minor extent, ore grade. The emanation rates of radon from mine walls and rocks may be estimated to determine which control measures to use and to establish design ventilation requirements. The large quantities of ventilation air, required to meet the federal standards for radon decay products within the mines, result in the discharge to the atmosphere of large air volumes with low radioactive concentrations. The immediate, large dilution of mine air by atmospheric air and the remote locations of the mines prevent any significant exposure to anyone. Normally, no special waste control equipment is needed to limit the discharge of radon and its decay products.

The thoron will be swept in the mine ventilation exhaust system as it is released from the mine. By continuously operating the ventilation system in the working areas, a thoron buildup can be prevented and the deposit of its daughters can be reduced.

The amount of thoron and its daughters being released to the environment via the ventilation system can be reduced by delaying the gas and filtering out the daughter particles in the exhaust system. If the air is exhausted at 500 ft/minute, the solid daughter particles will increase by about 50% (due to the 54.5 second half-life) within a 500-ft run of duct, shaft, drift, etc. in the ventilation system. The particulates can be collected by high-efficiency particulate-air (HEPA) filters before the air is discharged. Activated charcoal-filter delay traps could be used to collect essentially all of the thoron (99%+). After the thoron decays to the particulate daughter products, it will be released from the carbon filter and pass to the HEPA filter where 99.97% of the particulate will be collected. In the event that charcoal and HEPA filters are used, it will be necessary to install a baghouse filter upstream to catch the bulk of the dust.

Because of the high cost, it is probably impractical to use charcoal and HEPA filters in uranium mines. In a thorium mine, it may be practical because much less charcoal is needed and there is less of a pressure drop across the filter, reducing equipment and power costs.

4.1.4 Control of Equipment-Generated Fumes

No special methods will be used in the surface mines and all equipment (e.g., diesel engine) is assumed to utilize standard exhaust systems that meet or exceed EPA requirements. In the underground mines, the equipment fumes will be collected in the mine ventilation exhaust systems and diluted with excess air to meet EPA requirements.

4.2 METHODS OF ENVIRONMENTAL CONTROL FOR MILLING AND REFINING THORIUM

The generated wastes from the mill/refinery complex that may be released include:

- dust in the mill from unloading, crushing, and grinding the ore;
- dust from drying, ignition, and packaging the thoria;
- thoron gas released while the ore is unloaded, crushed, and ground in the mill;
- process fumes;
- waste sludge;
- tailings pond seepage;
- tailings pond beach dust;
- radioactivity in the tailings pond after the mill/refinery closes.

Airborne dust waste from the mill/refinery operations can be controlled with well-developed equipment. The control of the thoron from crushing and grinding operations in the mill (through the use of carbon and HEPA filters) is feasible but very expensive.

Waste control at the tailings pond, both during and after operations, still poses the biggest problem. Low-cost control methods that are effective against pond water seepage during operations need to be developed, as well as methods of curtailing long-term thoron release after the mill operations cease. Even the costly methods have site-specific problems.

4.2.1 Control of Mill Dust from Unloading, Crushing, and Grinding Ore

A large variety of well-developed equipment is available to control the waste dust. The equipment is gradually being improved and, as a result of the recent emphasis on environmental control, more special application equipment is on the market today. The application, location, ore characteristics, process selected, and other factors can determine the optimum choice of equipment. Probably no two plants will select the same equipment because of process and site-specific considerations.

The main types of dust collection equipment considered in this report are listed below. The list does not include all of the types of dust collectors that should be considered but is simply a cross section of equipment with various efficiencies. New pieces of equipment, hybrids of various types, are also coming onto the market.

In actuality, the dust collector should be selected after the process and plant layout is determined. Tests should be run with typical ore and conditions at the site to narrow down the equipment choice. Even with preliminary full-scale tests, unexpected surprises as a result of site-specific variables (e.g., ore moisture content, size fractions, climate extremes, etc.) may still occur after actual installation in the plant.

The types of dust collectors⁽⁵⁾ included in this study are as follows:

- Cyclone
- Orifice Scrubber
- Wet-impingement scrubber (irrigated target)
- Low-energy venturi scrubber
- High-energy venturi scrubber
- Baghouse filter
- HEPA filter
- Others.

4.2.1.1 Cyclone Dust Collector

A cyclone removes particulates from the air by converting the inlet stream into a double vortex within the cyclone. Figure 4.2 illustrates a

FIGURE 4.2. Cyclone⁽⁶⁾

cyclone dust collector.⁽⁶⁾ The primary vortex is formed as the inlet gas spirals downward and causes a layer of dust to slowly swirl down the walls and collect in the bottom of the hopper. Centrifugal force is the mechanism that acts to separate the particles. After the air reaches the bottom, the vortex reverses its axial direction and passes through the outlet. Multiple cyclones are simply two or more cyclones either in series or parallel. A single cyclone will have a collection efficiency of about 50% for 5-micron particles while multiple cyclones are up to 90% efficient.

A cyclone is simple in design and, therefore, has a relatively low cost. The collection efficiency is also relatively poor for particles below 10 microns in size. The cost of installing a 30,000-cfm cyclone is in the \$0.50 to \$1.00/cfm range.

4.2.1.2 Orifice Scrubber Dust Collector^(4,5)

Orifice scrubbers have been widely used in the uranium industry in the past. An example of an orifice scrubber is shown in Figure 4.3. Its principle of operation is that high-velocity air impinges on a pool of scrubbing

FIGURE 4.3. Orifice Scrubber (represented with permission from Environmental Engineers Handbook, Vol. 2 Air Pollution, Bela Liptak, Chilton Book Company, Radnor, Pennsylvania, 1974.

liquor. The air flows through a baffle at high velocity while carrying water in a heavy turbulent sheet. The rapid change in direction causes a centrifugal force that makes the dust particles penetrate and adhere to the water film. It has a dust collection efficiency of about 94% with 5-micron particles. The efficiency is reduced by about 50% for 1-micron sized particles. The installation costs range from approximately \$1 to \$2/cfm for a 30,000-cfm orifice-scrubber system.

4.2.1.3 Wet-Impingement Scrubber Dust Collector (Irrigated Target)

Figure 4.4 demonstrates a type of wet-impingement scrubber.⁽⁷⁾ The air stream is accelerated to a high velocity while passing through orifices, then impinged upon baffle plates. The dust particles are collected on vaned mist eliminators and are withdrawn, along with the solids collected, in the liquid overflow from the impingement plate. It has an efficiency of about 98% for 5-micron particles, which drops to about 80% for 1-micron particles. For a 30,000-cfm unit, the cost ranges from about \$1.50 to \$2.50/cfm installed.

FIGURE 4.4. Wet-Impingement Scrubber (reprinted with permission from Pollution Engineering Practice Handbook, Cheremisinoff and Young, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1976, p. 126.

4.2.1.4 Low- and High-Energy Venturi Scrubber Dust Collectors

An example of a venturi scrubber is given in Figure 4.5.⁽⁶⁾ Its principle of operation is that high-velocity air impinges on the liquid stream in the throat of a venturi-shaped section and atomizes the liquid into fine droplets, on which the dust particles are collected. The gas stream continues into a cyclonic separator where the particle-laden scrubbing liquor and the air are thoroughly separated by centrifugal force to complete the cleaning operation.

Both the low-energy and high-energy units collect over 99% of the 5-micron size particles. The low-energy units collect up to 96% of the 1-micron size

FIGURE 4.5. Venturi Scrubber⁽⁶⁾

particles and the high-energy unit collect up to 98%. The low-energy unit will cost in the \$1.75 to \$2.75/cfm range. A high-energy unit costs \$2 to \$3/cfm. The operating costs are relatively high for these units. The high-energy unit is especially costly because of the large amounts of power needed to compensate for the high pressure drop across the venturi.

4.2.1.5 Baghouse Filter Dust Collector

In the baghouse filter dust collector, illustrated in Figure 4.6,⁽⁶⁾ the dust-laden air flows through a porous woven or felted fabric where it deposits the particulates in the voids. The pressure drop gradually increases as the voids are filled. When it is necessary to clean the bags, this is accomplished by mechanical action such as shaking the bags or reverse air-jet pulsing. The dust falls into a hopper for subsequent disposal or recycling in the process. The particulates are collected dry and in a usable condition, so recovery is relatively easy. Bag filters operate best with relatively dry air streams. They cannot be used on such moist streams as the dryer off-gas.

Bag filters have an efficiency rating of up to 99.9%; some of the bags are even very efficient in removing submicron particles from the air. The installed cost of a simple 30,000-cfm baghouse filter system with shakers is about \$3 to \$5/cfm. The costs can be substantially higher if special bags, sophisticated cleaning methods, special alloys, etc., are needed.

4.2.1.6 HEPA Filter Dust Collectors

High-efficiency particulate air (HEPA) filters, shown in Figure 4.7, can be used downstream of a baghouse filter to reduce the release of particulates by practically 100%. Even small 0.3-micron size particles are removed with up to 99.97% efficiency. Excessive moisture, however, can impair the HEPA filter's efficiency. The periodic buildup of particulates require the removal and replacement of the HEPA filter units.

HEPA filters have been used for many years in the nuclear industry to effectively remove radioactive particulates from gas streams. Use of this type of filter in the mining industry was not found during our review.

Each HEPA filter has a capacity of about 1,000 to 3,000 cfm. For large air flows, it is necessary to arrange them in a parallel battery arrangement

FIGURE 4.6. Baghouse Filter⁽⁶⁾

FIGURE 4.7. HEPA Filter and Manifold Housing for Multiple Filters
(reprinted with permission from Flanders Air Filtration
Products Catalog, Flanders Filters, Washington, NC.

in a manifold housing, which spreads the air flow. The cost estimate for a 30,000-cfm unit installed would range from \$6 to \$10/cfm.

4.2.1.7 Other Types of Dust Collectors

There are many designs for each type of dust collector discussed so far; there are also many other types of dust collectors that have not been discussed. Some collectors are hybrids of different types; others are continually in the process of being designed and developed. Therefore, a more thorough review of available equipment should be made after site-specific data and ore samples are available for testing.

To select the proper dust collection equipment for a given site, it will be necessary--as a minimum--to know the following types of data:

- application
- volume, temperature, and moisture content at inlet
- inlet variations and outlet conditions
- corrosive characteristics
- particle size distribution of the dust
- dust grain loading
- physical and chemical characteristics of the material being collected
- cooling and heating requirement, if any
- scrubbing liquid characteristics and availability
- climate.

4.2.2 Control of Dust from Drying, Ignition, and Packaging Thoria

Essentially 100% of the daughters of thorium are removed from the thorium at this point in the process. The bulk of the particulates released from these process steps are thorium and water. While mostly water is given off in the drying and ignition steps, thoria is the only effluent exhausted from the packaging hoods.

The wet-type dust collectors such as orifice, wet-impingement, low-energy venturi, and high-energy venturi scrubbers can be used for the effluents from drying and ignition. Dry-type collectors, such as baghouse and HEPA filters, are used for the packaging operations.

The dust in this area is more radioactive and, therefore, it is impractical to use low-efficiency collectors like cyclones. The recovery of thorium particulates in this area of the refinery will sometimes more than pay for the dust collection equipment and operations involved.

4.2.3 Control of Thoron Gas from Unloading, Crushing, and Grinding

Thoron gas is released when the ore is crushed and ground. It will be difficult to control without the use of a delaying mechanism. Some of the gas released will decay into daughter particulates because of thoron's short half-life. The particulates can be collected by HEPA filters and, to a smaller extent, by baghouse filters. Wet scrubbing solutions might also collect some of the particulates (tests are needed to verify how much).

Activated charcoal filters would be used to collect thoron gas from the exhaust stream. The filter system would be similar to the one mentioned earlier for the underground mine exhaust. The activated charcoal would be placed in a module made up of several stacked trays of charcoal, which could handle a 1000-cfm air flow. These modules could be placed in a battery arrangement, similar to HEPA filters, for large air flows. Periodically, the trays would be recharged with fresh charcoal.

The charcoal filter station would be downstream from a baghouse filter, which would collect the bulk of the dust. A HEPA filter station would be placed downstream of the charcoal filters to collect thoron daughter and carbon particulates. The charcoal filter should delay up to 99+% of the thoron for subsequent recovery of 99+% of the daughter product in the HEPA filter.

The cost estimate for a 30,000-cfm charcoal filter system (including baghouse and HEPA filters) is in the \$15 to \$30/cfm range. This cost may be too high a price for the small amount of thoron and its daughters collected.

Some constraints that may make it difficult to use charcoal filters are:

- The relative humidity of air stream should be 50%.
- Shielding will be required because of the radioactivity.
- Charcoal beds are a potential fire hazard.
- Very limited data and experience are available for designing the system.

An alternative to collecting thoron with carbon filters would be the use of a refrigeration trap, but this is not considered practical for large air flows because of its high cost.

4.2.4 Process Fume Control

The processes considered in this study do not generate sufficient fumes to warrant the use of effluent control equipment. Minor fumes will be generated from low-temperature acids, kerosene, diesel, and other chemicals, but they can be handled with conventional ventilation equipment stacks.

In cases where high-temperature acids or other chemicals are used, it will be necessary to use fume scrubbers. Venturi scrubbers, packed-bed scrubbers, or mist eliminators can be used to control the fumes. They can be installed at a cost of \$1 to \$4/cfm.

4.2.5 Refinery Waste Sludge Control

Some of the refineries will generate a small volume of sludge. The following alternatives were considered for handling the sludge:

- trucking the sludge to an onsite landfill lined with 3 ft of clay (assumed as the base technology);
- blending the sludge with asphalt and trucking it to an unlined onsite landfill; or
- shipping the sludge to a federal licensed landfill.

In all of these cases, the sludge would likely be fed into a hopper for periodic removal from the refinery. A screw conveyor could be used to remove the sludge as required for the next step. It would be relatively simple to load and unload a truck or fork lift (equipped with a dumpster) with sludge for transport to the landfill. The landfill pit would be progressively covered as it became filled and dried out.

If asphalt is blended with the sludge, the landfill operation would remain about the same but the costs would be substantially higher for the added operation and the asphalt material. The main benefit would be a more stable landfill. As an alternative, concrete could be blended with the sludge at a lower cost, but this alternative was not included in the study.

Shipment of the sludge to a licensed burial ground involves loading the sludge into approved plastic-lined 55-gal drums. If necessary, excess solution can be absorbed by adding vermiculite or other absorbent materials to the drums. The drums are sealed and loaded onto special carrier trucks for shipment to the repository.

4.2.6 Tailings Seepage Control

Seepage from the tailings pond is generally minimized by a combination of proper site selection and careful design of the pond and dam. The seepage of water through the pond bottom and dam is still a common problem at many uranium tailings ponds. Seepage rates⁽⁸⁾ of 0 to 25% of the total input to the ponds have been reported. This seepage may be to the groundwater and/or to surface drainage. At many sites, some of the seepage is recovered in ditches or catch basins below the dam and pumped back to the pond. The newest mills have clay-core dams⁽⁴⁾ where seepage has not been observed. One new mill was projecting 12% to 27% seepage⁽¹¹⁾ even with a clay-core dam. This study has assumed the use of clay-core dams as its base technology.

The geological permeability at some sites will make it necessary to line pond bottoms with clay, asphalt, rubber liners, etc., to minimize or eliminate seepage. Neutralization of acidic mill water may be required to protect some of the liners (e.g., asphalt). Some of the main factors to be considered in evaluating the pond liners are:

- resistance to subsidence of subsoil and rock,
- resistance to chemical attack from tailings fluid,
- resistance to physical penetration (man, equipment, animals, waves, wind),
- resistance to weathering (freeze-thaw, bakeout, ultraviolet light, ozone),
- liner permeability,
- liner aging,
- microbial resistance, and
- liner pressure differential effects (water head, gas generation, etc.).

In addition to geological and liner factors, the coarseness of the tailings solids can have an influence on the seepage rates.⁽¹¹⁾ Finer particulates fill in voids and reduce seepage rates. Thorium mill/refineries are expected to generate a larger fraction of fines than do uranium mills.

Other methods of reducing seepage involve dewatering the tailings and burying them as sludge or as blends with concrete or asphalt. The excess water can be eliminated by evaporation in a lined pond or an evaporator, recycled to the mill, or some combination. Residue from the excess water would be collected and processed along with the tailings at the termination of the mill's operation.

Some innovations for handling mill tailings were presented at the recent annual uranium industry seminar.⁽¹⁰⁾ Additional innovations are encouraged since it is recognized that the problems of developing tailings management and disposal plans are highly site-specific.

4.2.6.1 Clay-Core Dam (Base Technology)

The base technology assumes that a dam is constructed across a natural valley or basin to impound the mill tailings and solutions. The dam is constructed of compacted borrow material with a clay core that is keyed to an impervious rock strata or clay at the base of the dam. Diversion ditches will be constructed to handle natural runoff around the impoundment. The pond bottom will be scarfed to remove topsoil that can be used in later reclamation procedures. The bottom will be contoured, smoothed--as much as practicable, and compacted. Hopefully, the site will have a native clay base.

A distribution system, such as a movable piping network, tremie rafts, a small dredge, etc., will be used to spread out the tailings and maintain a water cover on the tailings at all times. At all of the sites included in this study, a substantial amount of excess water is available to maintain a water cover over the tailings. The water cover will hold radon emanation to very low levels.

Some of the excess water (up to 80%) will be reused in the mill after passing through an auxiliary settling pond. Extra treatment of the recycle water, such as the addition of flocculants, lime, or barium chloride, may be required but they were not included in this study's costs.

The use of a clay-core dam should reduce seepage down to the 0 to 15% range. However, at some sites this low a seepage rate cannot be achieved even with clay-core dams.⁽¹¹⁾ The cost for a 100-acre tailings pond, distribution system, and recycling system would be about \$3,000,000.

4.2.6.2. Clay-Core Dam with Clay Liner

This case is the same as the base technology case except a 3-ft compacted clay liner is added to the bottom and the dam interface. It is assumed that good impermeable clay is readily available within a few miles of the site. If it is not, the clay-liner option would have to be carefully studied and compared to the other options. Additives that will make some permeable clays more impermeable are being developed but there was not enough information for their costs and effectiveness to be projected. During periods of drought and hot weather, steps must be taken to prevent cracks from developing in the clay.

The addition of a clay liner should reduce the seepage rate by a factor of 5 to 10, down to a 0 to 3% range. The cost of adding a 3-ft clay liner to a 100-acre dam would be a minimum of about \$350,000. If the clay is mined offsite and must be shipped to the site, this will add considerably to the cost.

4.2.6.3 Clay-Core Dam with Asphalt Liner

Except for the added asphalt liner and the neutralization plant, this case is the same as the base technology case. A 2-in. asphalt liner is laid on top of a 4-in. rock base over the entire pond bottom and the dam interface. A neutralization plant has also been added to neutralize the tailings acid water before it is exposed to the asphalt. The asphalt liner should reduce the seepage to less than 1%. The cost for a 100-acre liner will be about \$2,350,000. The cost of the neutralization plant will be about \$800,000. The development of asphalt emulsions⁽⁹⁾ to line the ponds may reduce the cost of liners appreciably in the future.

4.2.6.4 Clay-Core Dam with Rubber Liner

A 60-mil multi-ply rubber (hypalon or equivalent) liner is added to the bottom and dam surfaces of the tailings pond. In this process, extra care is taken to smooth the contours of the land and to remove sharp objects that

might penetrate the liner. Venting is added where natural gas might be a problem. If the rubber liners are well cared for and protected from foot and vehicular traffic, they should provide essentially 0% leakage for the life of the mill. The cost of lining a 100-acre pond with 60-mil hypalon would be about \$3,250,000.

4.2.6.5 Dewater Tailings, Convey to Landfill

A landfill pit well above the ground water is excavated and lined with about 3 ft of clay. The tailings stream will pass through neutralization, thickening, and vacuum filter steps to dewater the tailings. A covered conveyor belt system carries the tailings to the landfill. The excess water is pumped to a hypalon-lined storage pond. The water is recycled to the mill after passing through an auxiliary settling pond. Solids from the storage and settling ponds are transferred to the landfill when the mill is decommissioned.

The cost of a 100-acre landfill pit to serve a 1000-tpd mill would be about \$7,100,000. If a mined-out area can be used in lieu of excavating a landfill pit, about \$2,000,000 would be saved. At some sites, using trucks to haul the dewatered tailings to the landfill might also save money. Seepage from the tailings should be less than 1% for this option.

4.2.6.6 Dewater Tailings, Blend with 10% Cement, Pump to Landfill

A clay-lined landfill pit is used in lieu of a tailings pond to dispose of the tailings. The pit is lined with 3 ft of clay. The mill tailings stream passes through a neutralizing and thickening step where the solids are removed in a slurry. The slurry is mixed with about 1 part cement to 10 parts solids, then the slurry is pumped to the landfill where it is allowed to solidify. The decanted water from the thickener is pumped to a hypalon-lined storage pond. The water is recycled to the mill after passing through a secondary settling pond. Seepage from the original tailings effluents should be close to zero. After the mill is shut down, solids from the storage and settling pond are processed through the cement slurry plant for burial.

For a 1000-tpd plant, the installation cost of the above system will be \$5,200,000. Annual costs will be about \$3,400,000. The use of a mined-out pit could save about \$2,000,000 in excavation costs.

4.2.6.7 Dewater Tailings, Blend with 40% Asphalt, Truck to Landfill

Tailing solids are blended with asphalt and disposed of in an unlined landfill pit above the water table. The mill waste solutions are neutralized with slaked lime, dewatered in a thickener, and concentrated by a continuous filter. The tailing solids are blended with about 40% asphalt in an asphalt fixation plant, then the blend is hauled to the landfill by truck where it is dumped and compacted. The asphalt coats the tailing particles with a coating that is relatively impervious to leaching and thoron migration. The decanted water is processed for recycling, as in the other dewatered tailing cases.

The installation cost of the system outlined above is about \$12,400,000 for a 1000-tpd mill. If excavation can be eliminated, a cost savings of about \$3,500,000 would be achieved. The annual cost will be extremely high, about \$19,000,000, primarily due to the cost of the asphalt material.

4.2.7 Tailings Pond Beach Dust Control

Beach dust will be much less of a problem in the cases where tailings solids are dewatered and buried. The water storage pond liners will have to be periodically washed down around the water's perimeter.

In the cases where tailings ponds are used, more beach surface area will be exposed and will require more treatment. Unlined and clay-lined pond beaches will have to be periodically sprayed with chemical coating agents using portable equipment to tie down the dust washed up by waves. Beaches around ponds lined with asphalt or hypalon will probably require hosing down with water as a minimum. The cost of portable spray equipment is estimated at about \$20,000 for a 100-acre tailings pond. The effectiveness can be very good if the spraying is administered at the proper times.

As previously mentioned, the tailings are maintained underwater and thus there will be no exposed tailings pile to treat. The processes assumed in this study generated a large tailings solution-to-solids ratio and, since the

sites selected were not in arid parts of the country, they must either recycle water or add hundreds of extra acres to the ponds' size to assure adequate evaporation of the water. Recycling conserves the water; so there is also enough extra water to maintain a head over the tailings despite variations in mill waste rates, seasonal evaporation rates, retention system designs, and other cyclic factors.

4.2.8 Tailings Pond Thoron Gas Control

The release of thoron gas from the pond during the mill's operating life will be controlled by the same methods as the tailings dust: the tailings are kept underwater and the beaches are periodically cleaned or sprayed with crusting chemicals.

After the mill ceases its operations, the pond will be allowed to evaporate, leaving the tailings exposed once again. As soon as tailings become exposed, they will be tied down with chemicals or sprayed with water for an interim period. After the tailings are sufficiently dry, they will be covered with an appropriate cover for long-term stabilization of the thoron, tailings, and radioactivity. The long-term stabilization procedures are discussed in the following section.

4.2.9 Long-Term Stabilization of the Tailings

After the mill ceases operation, the tailings are stabilized by covering them. However, stabilization of the tailings in the landfill cases will progress as fast as the landfill is filled.

The bulk of the radioactivity from the original mined ore is located in the tailings. This includes the radioactivity from the small percentage of thorium that was not recovered and from the daughters of thorium that were originally in equilibrium with the thorium. Uranium and its daughters may also be included at some of the sites. The daughters of thorium-232 all have much shorter half-lives than the daughters of uranium-238. Thus, it is a great deal easier to stabilize thorium mill wastes than it is to stabilize uranium mill wastes.

Radioactivity from the original radium-228 and its daughters will be almost down to zero within 50 yr after the pile is stabilized. At that point, the bulk of the radioactivity will come from the residual thorium and uranium (if available) and their daughters.

The shorter half-life of thoron (radon-220), 54.5 seconds, versus 3.82 days for radon-222 will allow the thorium tailings covers to be much thinner than the uranium tailings covers (~factor of 6000 difference). Except for a difference in the half-lives, radon-220 and 222 will behave the same. Therefore, where a 1-ft earth cover reduces the radon emanation from uranium tailings only a minor amount, it should reduce emanation from thorium tailings by a major amount.

The pile should be leveled just prior to being covered. The cover should be crowned slightly in the middle to allow natural drainage away from the tailings and, thus, reduce the chance of leaching radioactive constituents into the groundwater. The cover should prevent radioactive particles from migrating and reduce the emanation of thoron to near background levels. The cover should also be thick enough to reduce above-ground radiation levels to as close as possible to background levels.

Besides contouring the cover to prevent the accumulation of runoff above the tailings, ditches and diversion dams should be installed to permanently control the runoff from the surrounding land. Most of the diversion system will be installed before the mill commences initial production.

The cover should have adequate protection from erosion by the wind and run-off water and from burrowing ground rodents. The cover can be topped with either rocks or vegetation. Rock riprap will prevent utilization of the land and protect the cover from wind erosion. Rock covers are especially suitable where moisture is inadequate to support vegetation.

Vegetation can be added to stabilize the cover, providing topsoil is also placed on the cover. Vegetation can probably be used at most of the thorium mining sites because adequate moisture is available. Care must be taken to avoid plant vegetation that will provide a path for the migration of radium

and thoron. Where roots are likely to penetrate the tailings, it may be necessary to install a barrier such as an asphalt lining, rubber lining, or other means hostile to the growth of vegetation into the tailings.

The cover may also incorporate a rubber lining, asphalt layer, or compacted-clay layer to reduce the permeability of the cover. The use of such layers will reduce the leaching potential of the tailings and will also substantially reduce the thickness of the earth cover needed to prevent thoron emanation. The development of asphalt emulsions⁽⁹⁾ to cover the pond may reduce the cost of covers appreciably in the future.

In this study, a variety of covers for the tailings were considered. They included 1- to 6-ft earth covers; a 1-foot compacted clay cover, a 1-in. asphalt cover, and a 60-mil hypalon (or equivalent) impermeable cover; and a rock or vegetation topping.

Costs for a 100-acre tailings pond cover range from \$320,000 for 1 ft of earth topped with 6 in. rock to about \$4,000,000 for 60-mil hypalon and 6-ft of earth, topped with 6 in. of rock.

The costs for the rock topping are higher than for the vegetation if no maintenance is required. If vegetation maintenance is required, that option will likely be the more costly in the long run. Costs will vary considerably between sites, especially if the rock or topsoil have to be mined offsite.

4.3 REFERENCES

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5.0 RELATIVE COST AND EFFECTIVENESS ESTIMATES FOR ENVIRONMENTAL CONTROL TECHNOLOGIES

The cost and effectiveness of the technologies discussed in the previous section are estimated for the mining, milling, and refining of the various thorium resources outlined in this section. These estimates can be used for preliminary planning and analysis but more accurate costs and estimates of effectiveness will have to be determined during the site-specific feasibility and environmental impact studies or during the preliminary plant design.

The estimates are based on a general review of the literature^(1,2,3,4,5) and augmented by discussions with sales engineers in some cases. The vendors all cautioned that, in order to make accurate ($\pm 30\%$) estimates, it is necessary to have an accurate assessment of process and layout, thorough ore characterization, and site-specific (e.g., climate, geology, water availability, etc.) and other data available. Preliminary laboratory and full-scale tests should also be run when practicable. Sometimes, even with thorough advance testing, some surprises occur at the startup of production. Production downtime alone may be of enough importance to sway a decision on which method or system to use.

The control methods analyzed in this study represent a cross-sectional comparison of methods in various stages of advancement. Because the technology of dust collection is well advanced, there is a wide selection of hardware designs. The dust collection methods included in this study represent a selection of some of the many methods, which range in efficiency from high to low. On the other hand, the technology for tailings storage is not as well advanced. Both conventional tailings storage methods and more advanced, but less tested, methods have been included in this study.

The estimated cost range for the seven thorium resource sites considered in this study are summarized in Table 5.1. Details on the cost and effectiveness of various environmental control technologies are provided in Tables 5.2, 5.3, and 5.4.

Table 5.1 indicates that the range of costs at each site can vary by up to two orders of magnitude. The lower end of the cost spectrum represents the

use of the most simple, least costly, and usually least effective environmental control technologies. In this study, the lowest cost represents the base technology case. The upper end of the cost spectrum utilizes the most sophisticated, most costly, and usually most effective technologies. However, some of the more advanced and costly technologies will require testing and actual use in the field before their effectiveness can be accurately assessed. The large contingency of up to 200% can apply because geologies may have adverse variations, special materials may be required in equipment construction, or larger equipment capacities or additional equipment may be required due to the nature of the ore or processes selected.

TABLE 5.1. Cost Range for Environmental Control for the Mining, Milling, and Refining of Various Thorium Resources

<u>Location</u>	<u>Aproximate Cost Range Cost/lb of Thoria Produced(a,b)</u>
Lemhi Pass	\$0.63 to \$40.65
Hall Mountain	\$0.28 to \$16.35
Wet Mountain	\$0.34 to \$18.96
Palmer, Michigan	\$0.46 to \$ 2.13
Bald Mountain	\$4.29 to \$26.22
Conway Granite	\$0.43 to \$ 4.56
Stockpile Refinery ^(c)	\$0.15 to \$ 1.98

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- (a) Maximum cost is for the more effective but usually more complex methods and includes up to a 200% contingency on estimates.
- (b) Minimum cost represents the base technology, which is usually the most available, lowest cost, and simplest to employ (e.g., equipment constructed of mild steel, easy to move soil, good onsite availability of construction materials, no special protection from the environment, low contingency, etc.).
- (c) Does not include mining and milling environmental control costs.

TABLE 5.2. Cost and Effectiveness of Environmental Control Technologies at Lemhi Pass, Hall Mountain, and Wet Mountain

Generated Waste and Control Method	Lemhi Pass Cost Estimates(a)		Hall Mountain Cost Estimates(a)		Wet Mountain Cost Estimates(a)		Estimate of Relative Effectiveness(b)	Technology Confidence Level(b)
	Capital Cost	Annual Cost	Capital Cost	Annual Cost	Capital Cost	Annual Cost		
• Mine Water								
Settling Pond (Base)	\$ 35,200	\$ 11,100	\$ 21,700	\$ 9,700	\$ 21,700	\$ 9,700	30% to 90% Solids Settle	High
Add Flocculation and Clarification	292,700	123,300	180,200	94,100	180,200	94,100	TSS Reduced 97%, COD Reduced by 86%, Radium Reduced 99%	High
Add Ion Exchange	473,000	163,600	288,500	135,700	288,500	135,700	Recovers 92% of Thorium	Low
Add Barium Chloride Coprecipitation	41,700	52,800	25,400	32,400	25,400	32,400	Radium Reduced 99.9%	High
Add Lime Neutralization	141,000	70,500	86,000	52,700	86,000	52,700	Precipitates Heavy Metals, Increases pH, Helps Remove Radium	High
Total If All Methods Used	983,600	421,300	601,800	324,600	601,800	324,600		
• Controlled Mine Ore Dust and Thoron (Underground)								
W/O Control Equipment (Base)	0	0	0	0	0	0	No Dust or Thoron Reduction	--
Add Baghouse Filter	892,000	464,000	522,800	361,200	466,700	320,600	99.9+% Dust Reduction	High
Add HEPA Filter (Includes Baghouse Filter)	2,697,000	1,199,000	1,580,000	954,300	1,410,700	847,600	99.99+% Dust Reduction	Medium
Add Charcoal Filter (Incl. Baghouse & HEPA Filters)	4,821,000	1,932,000	2,825,000	1,558,900	2,521,500	1,385,900	99.99+% Dust Reduction and 99+% Thoron Reduction	Low
• Uncontrolled Dust (Surface)								
Spray Road, Yard and Loading/Unloading Areas (Base)	30,000	29,200	17,300	18,500	16,000	17,200	30% to 95% Dust Reduction	High
Ore Pile Wind Barriers (Base)	15,000	5,000	8,700	4,200	8,000	3,700	20% to 60% Dust Reduction	High
Ore Pile Storage Buildings	60,000	16,200	34,600	14,200	32,000	13,200	80% to 100% Dust Reduction	High
• Mill Loading, Crushing and Grinding Dust and Thoron								
Cyclone Dust Collector (Base)	19,900	11,600	13,500	10,200	11,100	7,800	50% Dust Reduction	High
Orifice Scrubber	39,800	21,500	29,200	17,900	22,100	13,400	94% Dust Reduction	High
Wet-impingement Scrubber	47,800	23,400	35,100	22,900	26,500	17,200	97% Dust Reduction	High
Low-Energy Venturi Scrubber	55,800	32,600	41,000	29,300	30,900	21,800	99+% Dust Reduction	High
High-Energy Venturi Scrubber	67,700	53,000	49,700	44,800	37,600	33,200	99+% Dust Reduction	High
Baghouse Filter	111,600	51,700	81,900	49,100	61,900	36,900	99.9+% Dust Reduction	High
HEPA Filter (Includes Baghouse Filter)	337,400	140,100	247,700	131,300	187,100	102,700	99.99+% Dust Reduction	Medium
Charcoal Filter (Includes Baghouse & HEPA Filter)	603,100	228,800	442,700	223,600	334,400	172,100	99.99+% Dust Reduction and 99+% Thoron Reduction	Low
• Refinery Drying and Ignition Dust								
Wet-impingement Scrubber (Base)	39,900	20,400	46,200	30,500	38,300	25,000	97% Dust Reduction	High
Low-Energy Venturi Scrubber	46,500	26,800	53,900	39,000	44,600	39,100	99+% Dust Reduction	High
High-Energy Venturi Scrubber	56,500	43,600	65,500	60,400	54,200	49,300	99+% Dust Reduction	High
• Refinery Packaging Dust								
Baghouse Filter (Base)	22,700	9,900	24,700	14,300	20,300	11,800	99.9+% Dust Reduction	High
HEPA Filter (Includes Baghouse Filter)	68,700	27,400	74,700	39,800	61,400	32,600	99.99+% Dust Reduction	High
• Tailings								
Clay Core Dam w/o Lining (Base)	3,066,000	913,400	970,000	449,700	902,200	416,900	0% to 15% Seepage	High
Clay Core Dam w/3 ft Clay Liner	3,416,000	999,300	1,046,700	479,300	974,800	444,900	0% to 3% Seepage	Medium
Clay Core Dam w/Asphalt Liner	6,227,000	1,866,100	1,662,300	777,400	1,556,500	669,800	0% to 1% Seepage	Low
Clay Core Dam w/Rubber(c) Liner	6,296,000	1,705,600	1,677,400	723,100	1,570,800	675,300	0% to 0.2% Seepage(g)	High
Dewater, Convey to Landfill	7,102,500	2,146,200	2,721,900	1,230,600	2,469,600	1,114,000	0% to 0.1% Seepage(g)	Medium
Dewater, Blend w/10% Cement, Pump to Landfill	6,487,400	3,721,700	2,310,100	1,809,800	2,107,400	1,622,500	0% to 0.08% Seepage(g)	Low
Dewater, Blend w/40% Asphalt, Truck to Landfill	12,388,600	19,203,300	5,185,000	8,527,100	4,684,000	7,529,500	0% to 0.06% Seepage(g)	Low
• Tailings Beach Dust								
Spraying w/Dam Case (Base)	20,000	26,000	11,500	16,000	10,700	14,700	50% to 95% Effective	Medium
Spraying w/Dewatering Case (Base)	10,000	13,000	5,800	8,000	5,800	7,400	50% to 95% Effective	Medium
• Tailings Cover Summary(d)								
1 ft Earth w/Rock Cover(e) (Base)	320,000(f)	1,000(f)	70,100(f)	10,400(f)	66,400(f)	9,800(f)	1 (Base)	High
6 ft Earth w/Rock Cover	920,000	2,800	201,700	29,900	190,400	28,200	10 Times as Effective	High
6 ft Earth w/Vegetation	800,000	2,400	175,400	26,000	105,600	24,600	<10 Times as Effective	Medium
1 ft Clay w/Rock Cover(e)	325,000	1,000	71,200	10,600	67,300	10,000	10 Times as Effective	Medium
1 ft Clay, 6 ft Earth w/Rock Cover	1,045,000	3,200	229,000	34,000	216,300	32,100	20 Times as Effective	Medium
1 ft Clay, 6 ft Earth w/Vegetation	925,000	2,800	202,800	30,100	191,500	28,400	<20 Times as Effective	Medium
1 in. Asphalt w/Rock Cover(e)	1,500,000	4,600	328,800	48,800	310,500	46,100	Subject to Frost/Heaves	Low
1 in. Asphalt, 6 ft Earth w/Rock Cover	2,220,000	6,800	486,600	72,200	459,500	68,200	310 Times as Effective	Medium
1 in. Asphalt, 6 ft Earth w/Vegetation	2,100,000	6,400	460,300	68,300	434,700	64,500	<310 Times as Effective	Medium
60 Mil Rubber(c) w/Rock Cover(e)	3,430,000	10,500	751,900	111,500	710,000	105,300	300 Times as Effective	Medium
60 Mil Rubber(c), 6 ft Earth w/Rock Cover	4,115,000	12,700	909,700	134,900	859,000	127,400	310 Times as Effective	Medium
60 Mil Rubber(c), 6 ft Earth w/Vegetation	4,030,000	12,300	883,400	131,000	834,200	123,700	<310 Times as Effective	Medium
Cost Summary								
Minimum Cost	\$ 3,568,700	\$ 1,027,600	\$ 1,183,700	\$ 563,500	\$ 1,094,700	\$ 516,600		
Maximum Cost	\$23,136,500	\$21,987,100	\$10,162,100	\$10,910,000	\$ 9,170,100	\$ 9,659,200		
Production, Pounds 99% Thorium		1,623,132 lbs		2,002,000 lbs		1,529,000 lbs		
Minimum Cost/Pound 99% Thorium		\$ 0.63/lb		\$0.28/lb		\$0.34/lb		
Maximum Cost/Pound 99% Thorium		\$13.55/lb		\$5.45/lb		\$6.32/lb		

- Notes: (a) Costs could go up to 3 times as high for some sites because of variables in site and process characteristics.
(b) These are mostly the best estimates based upon literature written for the uranium industry and extrapolated to the thorium industry.
(c) Multi-Ply Hypalon or equivalent material.
(d) All of these cases should hold thoron release to levels close to background. They should also eliminate release of radioactive particulates.
Assumptions: 6 ft Earth reduces thoron emanation by factor of 11 from no cover.
10 ft Earth reduces thoron emanation by factor of 50 from no cover.
1 in. Asphalt equivalent to 60" of earth cover.
60 mil rubber is equivalent to 1" asphalt.
(e) Radiation levels will likely be well above background initially and decay down to background levels after 50 years. Remainder of cases will likely be close to background at all times.
(f) Tailings cover capital costs are incurred after the refinery closes down. A sinking fund is established to pay for the cover.
(g) Includes an allowance for water storage pond leakage also.

TABLE 5.3. Cost and Effectiveness of Environmental Control Technologies at Palmer, Michigan, and Bald Mountain

Generated Waste and Control Method	Palmer, Michigan Cost Estimates(a)		Bald Mountain Cost Estimates(a)		Estimate of Relative Effectiveness(b)	Technology Confidence Level(b)
	Capital Cost	Annual Cost	Capital Cost	Annual Cost		
• Mine Water						
Settling Pond (Base)	235,800	100,700	174,700	78,300	30% to 90% of Solids Settle	High
Add Flocculation and Clarification	631,600	277,200	474,400	217,300	TSS Reduced 97%, COD Reduced by 86%, Radium Reduced 99%	High
Add Ion Exchange	1,020,700	323,300	768,600	284,900	Recovers 92% of Thorium	Low
Add Barium Chloride Coprecipitation	90,000	136,500	67,800	97,800	Radium Reduced 99.9%	High
Add Lime Neutralization						
Total If All Methods Used	304,300	153,200	229,100	120,100	Precipitates Heavy Metals, Increases pH, Helps Remove Radium	High
• Uncontrolled Dust-Mine to Mill						
Spray Roads, Yards, Loading Areas (Base)	60,000	73,600	47,000	52,700	30% to 95% Dust Reduction	High
Ore Pile Wind Barriers (Base)	96,000	30,800	47,400	18,600	20% to 60% Dust Reduction	High
Ore Pile Buildings	562,600	146,200	238,900	70,500	80% to 100% Dust Reduction	High
• Mill Unloading and Crushing Dust						
Cyclone Dust Collectors (Base)	138,900	87,700	34,700	26,700	50% Dust Reduction	High
Orifice Scrubbers	277,900	148,700	69,500	42,800	94% Dust Reduction	High
Wet-Impingement Scrubbers	333,500	195,700	83,400	56,300	97% Dust Reduction	High
Low-Energy Venturi Scrubbers	389,100	260,500	97,300	75,000	99+% Dust Reduction	High
High-Energy Venturi Scrubbers	472,500	440,500	118,100	127,000	99+% Dust Reduction	High
Bag Filters	632,000	351,000	194,500	116,200	99.9+% Dust Reduction	High
• Mill Drying, Magnetic, Separation, and Loading Dust						
Wet-Impingement Scrubber (Base)	108,000	66,700	54,000	35,000	97% Dust Reduction	High
Low-Energy Venturi Scrubber	126,000	90,200	63,000	47,100	99+% Dust Reduction	High
High-Energy Venturi Scrubber	153,000	152,500	76,500	78,900	99+% Dust Reduction	High
• Mill Separation and Dewatering Liquid						
Clay-Lined Pond w/Recycle (Base)	7,219,800	2,293,700	2,347,600	794,600	0% to 3% Seepage, Not Very Radioactive	Medium
• Refinery Unloading and Grinding Dust and Thoron						
Cyclone (Bald Mt. Base)	--	--	8,800	6,100	50% Dust Reduction	High
Baghouse Filter (Palmer Base)	49,500	23,900	49,500	27,200	99.9+% Dust Reduction	High
HEPA Filter (Includes Baghouse Filter)	149,700	66,400	149,700	73,800	99.99+% Dust Reduction	Medium
Charcoal Filter (Includes Baghouse & HEPA Filters)	267,600	108,500	267,600	120,000	99.99+% Dust Reduction plus 99+% Thoron Reduction	Low
• Refinery Ignition and Drying Dust						
Low-Energy Venturi Scrubber (Base)	36,900	25,100	16,000	10,000	99+% Dust Reduction	High
High-Energy Venturi Scrubber	44,800	41,200	19,500	17,400	99+% Dust Reduction	High
• Refinery Packaging Dust						
Baghouse Filter (Base)	17,800	7,700	8,200	4,200	99.9+% Dust Reduction	High
HEPA Filter (Includes Baghouse Filter)	53,800	22,500	16,600	7,200	99.99+% Dust Reduction	Medium
• By-Product Recovery Dust						
Wet-Impingement Scrubber (Base)	44,700	26,900	30,000	18,700	97% Dust Reduction	High
Low-Energy Venturi Scrubber	52,100	35,900	35,000	24,700	99+% Dust Reduction	High
High-Energy Venturi Scrubber	63,300	60,000	42,500	40,400	99+% Dust Reduction	High
• Refinery Tailings Pond(e)						
Clay-Lined Pond (Base)	993,500	422,900	209,300	62,100	0% to 3% Seepage	Medium
Rubber(c) Lined Pond	2,044,000	680,800	576,300	180,600	0% to 0.2% Seepage	High
• Tailings Beach Dust						
Spraying (Base)	6,500	5,800	4,000	2,600	50% to 95% Effective	Medium
• Tailings Pond Cover(d)						
6 ft Earth w/Rock Cover (Base)	253,900(g)	2,500(g)	96,900(g)	4,800(g)	1 (Base)	High
6 ft Earth w/Vegetation(f)	220,800	2,200	84,000	4,100	<1 Times as Effective	Medium
1 ft Clay, 6 ft Earth w/Rock Cover	288,400	2,800	109,700	5,400	2 Times as Effective	High
1 ft Clay, 6 ft Earth w/Vegetation(f)	255,300	2,500	97,100	4,800	<2 Times as Effective	Medium
1 in. Asphalt, 6 ft Earth w/Rock Cover	612,700	6,000	233,100	11,500	31 Times as Effective	High
1 in. Asphalt, 6 ft Earth w/Vegetation(f)	579,600	5,600	220,500	10,900	<31 Times as Effective	Medium
60 Mil Rubber(c), 6 ft Earth w/Rock Cover	1,145,400	11,200	435,800	21,500	31 Times as Effective	High
60 Mil Rubber(c), 6 ft Earth w/Vegetation(f)	1,112,300	10,900	423,200	20,800	<31 Times as Effective	Medium
Cost Summary						
Minimum Cost	\$ 9,227,400	\$3,167,700	\$3,065,700	\$1,130,400		
Maximum Cost	\$14,535,200	\$4,937,900	\$5,981,400	\$2,301,000		
Production, Pounds 99% Thorium		6,953,337 lbs		263,175 lbs		
Minimum Cost/Pound 99% Thorium		\$ 0.46/lb		\$ 4.29/lb		
Maximum Cost/Pound 99% Thorium		\$ 0.71/lb		\$ 8.74/lb		

Notes: (a) Costs could go up to 3 times as high for some sites because of variables in site and process characteristics.
(b) These are mostly the best estimates based upon literature written for the uranium industry and extrapolated to the thorium industry. The values could vary substantially by site. Full-scale tests would be required to get more accurate data.
(c) Multi-Ply Hypalon or equivalent material.
(d) All of these cases eliminate release of radioactive dust unless breached some way. Also, radioactivity and thoron should be close to background levels.
(e) Only Palmer plant recycles the water to the refinery.
(f) Assumes no vegetation care is required. Slightly higher radioactivity and thoron release if roots penetrate to tailings.
(g) Tailings cover capital costs are not incurred until after the refinery shuts down. A sinking fund is established to pay for the cover.

TABLE 5.4. Cost and Effectiveness of Environmental Control Technologies at Conway Granite and Stockpile Refinery

Generated Waste and Control Method	Conway Granite Cost Estimates ^(a)		Stockpile Refinery Cost Estimates ^(a)		Estimate of Relative Effectiveness ^(b)	Technology Confidence Level ^(c)
	Capital Cost	Annual Cost	Capital Cost	Annual Cost		
• Mine Water						
Settling Pond (Base)	\$ 293,000	\$ 153,200			30% to 90% Solids Settle	High
Add Flocculation and Clarification	770,600	412,000			TSS Reduced 97%, COD Reduced by 86%, Radium Reduced 99%	High
Add Ion Exchange	1,248,200	476,600			Recovers 92% of Thorium	Low
Add Barium Chloride Coprecipitation	110,000	240,800			Radium Reduced 99.9%	High
Add Lime Neutralization	372,100	231,600			Precipitates Heavy Metals, Increase pH, Helps Remove Radium	High
Total If All Methods Used	2,793,900	1,514,200				
• Uncontrolled Dust						
Spray Roads, Yard, Loading Areas (Base)	75,000	125,000			30% to 95% Dust Reduction	High
Ore Pile Wind Barriers (Base)	150,000	44,100			20% to 60% Dust Reduction	High
Ore Pile Buildings	950,900	247,900			80% to 100% Dust Reduction	High
• Mill Unloading, Crushing & Grinding Dust						
Cyclones (Base)	69,500	53,000			50% Dust Reduction	High
Baghouse Filters	389,100	221,300			99.9+% Dust Reduction	High
• Mill Drying & Packaging Dust						
Wet-impingement Scrubber (Base)	54,000	34,900			97% Dust Reduction	High
Low-Energy Venturi Scrubber	63,000	45,500			99+% Dust Reduction	High
High-Energy Venturi Scrubber	76,500	77,300			99+% Dust Reduction	High
• Mill Tailings Pond						
Clay-Lined Pond w/Recycle (Base)	908,300	368,400			0% to 3% Seepage, Not Very Radioactive	Medium
• Refinery Waste Sludge						
Truck to Clay-Lined Landfill (Base)	178,500	65,500	157,100	57,600	0% to 0.04% Seepage	Medium
Blend w/Asphalt, Truck to Landfill	459,800	367,100	404,600	323,100	0% Seepage	Low
Ship to Barnwell, S.C.	25,000	707,700	25,000	466,500	0% Seepage	High
• Refinery Drying & Packaging Dust						
Bag Filter and HEPA Filter (Base)	186,800	90,600	103,700	45,500	99.99+% Dust Reduction	High
• Refinery Tailings Pond						
Clay-Lined Evaporation Pond (Base)	326,800	86,000	164,000	43,100	0% to 3% Seepage	Medium
Rubber ^(c) Lined Evaporation Pond	972,900	244,700	503,800	126,600	0% to 0.2% Seepage	High
• Refinery Tailings Beach Dust						
Spraying (Base)	4,000	3,100	4,000	2,400	50% to 95% Effective	Medium
• Refinery Tails Pond Cover ^(d)						
6 ft Earth w/6 in. Rock Cover (Base)	145,800 ^(f)	1,400 ^(f)	70,100 ^(f)	700 ^(f)	1 (Base)	High
6 ft Earth w/Vegetation ^(e)	126,800	1,200	60,900	600	<1 Times as Effective	Medium
1 ft Clay, 6 ft Earth w/Rock Cover	165,600	1,600	79,400	800	2 Times as Effective	High
1 ft Clay, 6 ft Earth w/Vegetation ^(e)	146,600	1,400	70,300	700	<2 Times as Effective	Medium
1 in. Asphalt, 6 ft Earth w/Rock Cover	351,900	3,400	168,700	1,600	31 Times as Effective	High
1 in. Asphalt, 6 ft Earth w/Vegetation ^(e)	332,900	3,200	159,600	1,600	<31 Times as Effective	Medium
60 Mil Rubber, ^(c) 6 ft Earth w/Rock Cover	657,800	6,400	315,400	3,100	31 Times as Effective	High
60 Mil Rubber, ^(c) 6 ft Earth w/Vegetation ^(e)	638,800	6,200	306,300	3,000	<31 Times as Effective	Medium
Cost Summary						
Minimum Cost	\$2,391,700	\$1,025,200	\$489,700	\$149,200		
Maximum Cost	\$7,475,000	\$3,606,600	\$1,322,400	\$639,100		
Production, Pounds 99% Thoria		2,376,605 lbs		965,580 lbs		
Minimum Cost/Pound 99% Thoria		\$ 0.43/lb		\$ 0.15/lb		
Maximum Cost/Pound 99% Thoria		\$ 1.52/lb		\$ 0.66/lb		

Notes: (a) Costs could go up to 3 times as high for some sites because of variables in site and process characteristics.
(b) These are mostly the best estimates based upon literature written for the uranium industry and extrapolated to the thorium industry.
(c) Multi-Ply Hypalon or equivalent material.
(d) All of these cases eliminate release of radioactive dust unless breached some way. Also, radioactivity and thoron should be close to background levels.
(e) Slightly higher radioactivity and thoron release if roots penetrate to tailings. Assumes no vegetation care is required.
(f) Tailings cover capital costs are not incurred until after the refinery shuts down. A sinking fund is established to pay for the cover.

Tables 5.2, 5.3, and 5.4 contain estimates of the capital cost, annual cost, relative effectiveness, and technology confidence level for each generated waste and environmental control method assumed. The base technology method for each waste is identified in the tables. The cost summaries for Tables 5.2, 5.3, and 5.4 cannot be directly compared to each other because they contain data for different types of resources that use different processes.

Table 5.2 summarizes data for underground thorite mine resources with relatively high-grade ore (0.35% to 1.1% thoria). Lemhi Pass is more costly than Hall Mountain and Wet Mountain primarily because it has a much lower grade of thoria.

Table 5.3 summarizes the data for open-pit conglomerate mine resources with low grades of thoria (0.0095% to 0.06%). The Palmer, Michigan, environmental control costs are much lower than at Bald Mountain because the Palmer, Michigan, operation uses a higher grade of ore and a higher throughput.

Table 5.4 compares only the Conway Granite resource refinery with the stockpile refinery. The unit environmental costs for the two refineries are essentially the same.

The effectiveness of the technologies used in this study have the potential of holding offsite discharge of effluents to very low levels. As can be observed from the tables, the more effective technologies usually cost more. An example of how costs rise with effectiveness is shown in Figure 5.1, which represents the methods for controlling dust from unloading, crushing, and grinding the ore at the Lemhi Pass mill.

5.1 COST ESTIMATES FOR ENVIRONMENTAL CONTROL TECHNOLOGIES

The cost estimates for all of the thorium mine sites are summarized in Tables 5.2, 5.3, and 5.4. The capital costs include the total installation costs. The constituent factors used are itemized in Section 5.1.1. The annual costs include all of the operating costs (Section 5.1.2), allowances for annual depreciable fixed charges, and a fixed charge for land and working capital, which are explained in Sections 5.1.3 and 5.1.4. Examples of calculations are provided in Appendices E and F.

FIGURE 5.1. Lemhi Pass Mill Unloading, Crushing, and Grinding Dust Collection Capital Costs as a Function of Efficiency

5.1.1 Capital Installation Cost

The capital cost of installing the equipment in this report is comprised of the following elements:

<u>Direct Costs</u>	<u>Factor (%)^(a)</u>
Purchased Equipment - Delivered	100
Equipment Installation	41
Instrumentation and Controls	13
Piping (Installed)	31
Electrical (Installed)	<u>10</u>
Total Direct Plant Cost	195
<u>Indirect Costs</u>	
Engineering and Supervision	32
Construction Expenses	<u>34</u>
Total Indirect Plant Cost	66
Contractor's Fee (5% of DPC & IPC)	13
Contingency (10% of DPC & IPC)	<u>26</u>
Total Capital Installation Cost	<u><u>300</u></u>

(a) Based on the values in Reference 3 and rounded off for calculation.

The land required for a specific facility (e.g., tailings pond) is costed out at the purchase price and is included in the cost estimate. The cost of installing the items that contain no equipment (e.g., settling pond) include the costs of construction plus 20% for project costs.

5.1.2 Operating Costs

The operating costs include the costs of operating labor, maintenance, materials, power, and miscellaneous items. The cost of the operating labor includes these constituents:

Labor	\$8.70/hr
Direct Supervision and Clerical (15% of Labor)	1.31/hr
Laboratory Charges (15% of Labor)	1.31/hr
Plant Overhead	7.05/hr
Administration Overhead	<u>1.76/hr</u>
Total Operating Labor Cost	\$20.13/hr

The maintenance costs were usually taken as a flat percentage (1% to 6%) of the capital installation cost. Whenever possible, the man hours were estimated and costed out at \$20.13/hr, which included an allowance for replacement parts. In cases where major maintenance replacement components were required, the costs were itemized separately (e.g., filter bags for baghouses). The major materials routinely consumed in the environmental control process were also itemized and costed separately, (e.g., lime, cement, asphalt, etc.). Power consumption was estimated in terms of kilowatt hours and it was costed out at \$0.03/kWh. The miscellaneous category included contingency and other items (e.g., special supplies, parts, etc.) that were inexpensive and general in nature.

5.1.3 Equivalent Annual Charge for Depreciable Capital Investment

A fixed rate was applied to convert a depreciable capital investment into an equivalent annual revenue requirement. Rather than calculate a year-by-year cash flow, a single fixed charge rate is assumed to apply over the life of the facility. The fixed charge rate includes provisions for capital recovery, bond interest, return on equity, federal income tax, state income tax, property tax, and property insurance. The fixed charge rate was calculated for the facility assuming financial conditions typical for a uranium mining company. For such a company, the data in Table 5.5 were assumed.

TABLE 5.5. Depreciable Capital Investment

	(%)
Capitalization	
Debt	24
Equity	76
Bond Interest Rate	8
Return on Equity	15
Federal Income Tax	48
State Income Tax	7
Property Tax	2.5 of Capital Cost
Property Insurance	0.5 of Capital Cost
Mine/Mill Life	Site Dependent
Depreciation	Sum-of-the-Year's-Digits Method

When the factors assumed in Table 5.5 were used, the following annual capital charge rates were calculated:

<u>Facility Life</u>	<u>Rate</u>
5 yr	0.3681
10 yr	0.2668
12 yr	0.2529
14 yr	0.2441
20 yr	0.2338
28 yr	0.2336

The rate was simply multiplied by the capital installation cost to give the annual charge for depreciable capital.

5.1.4 Equivalent Annual Charge for Nondepreciable Capital Investment

The fixed charge described in Section 5.1.3 does not apply to nondepreciable assets, which include land and working capital. In this study, it was assumed that a cost equivalent to 5% of the depreciable investment would

represent the annual land and working capital charge. This cost rate was used because the charge is minor, and it simplified the many calculations performed in this study.

5.1.5 Annual Cost

The annual cost is the sum of the operating cost, the annual depreciable charge, and the annual nondepreciable charge. This cost provides the economic comparison between methods for total costs on an annual basis.

5.2 EFFECTIVENESS ESTIMATES FOR ENVIRONMENTAL CONTROL TECHNOLOGIES

The effectiveness of the various environmental control technologies can vary considerably between sites. Like the costs for control, the effectiveness estimates are order-of-magnitude-type approximations. The effectiveness estimates for all of the thorium mine, mill, and refinery sites are summarized in Tables 5.2, 5.3, and 5.4.

5.2.1 Control of Airborne Dust from Productive Equipment

To control the dust effluents from mine ventilation, loading, crushing, grinding, by-product recovery, drying, ignition, and packaging-type operations, the list of equipment in Table 5.6 was assumed. The list provides a guide for a preliminary relative comparison of the equipment's dust collection efficiency only. The actual efficiencies of the equipment are likely to be lower because the dust grain loadings of waste air assumed in this study are lower than needed for the equipment to perform optimally.

5.2.2 Control of Airborne Dust From Roads and Yards

Road and yard dust can be controlled by tying down the dust with moisture or chemicals. The frequency and amount of spraying depends on the weather, amount of usage, type of dust, type of surface, etc. If rigidly administered, the dust in these areas should be controlled with close to 100% effectiveness although costs may become prohibitive.

5.2.3 Control of Airborne Dust From Ore Storage Piles

The primary method of protecting the ore storage piles from wind erosion is to erect prevailing wind barriers or store the ore in buildings. With some

TABLE 5.6. Dust Collector Efficiency Estimates⁽³⁾

<u>Type of Equipment</u>	<u>Collection Efficiency (%)</u>	
	<u>5 Micron Particles^(a)</u>	<u>1 Micron Particle</u>
Cyclone	50	--
Orifice Scrubber	94	50
Wet-Impingement Scrubber	97	80
Low-Energy Venturi Scrubber	99+	96
High-Energy Venturi Scrubber	99+	98
Baghouse Filter	99.9+	99+
HEPA Filter	99.99+	99.97+

(a) This study assumed the nominal particle size for dust was 5 microns.

types of ore and localities, it may be satisfactory to keep the ore tied down with water spray or to use the spray in conjunction with barriers. It was assumed in this study that a two-sided barrier located on the side of the most prevailing winds would be 20% to 60% effective in reducing dust. If supplementary spraying were used, a greater than 60% dust reduction is possible. The dampness would also reduce the release of dust from subsequent handling operations. The use of a full-scale building is estimated to be 80% to 100% effective in holding down the dust. However, when high-grade ore is used, the building would need some ventilation to maintain low thoron levels.

5.2.4 Control of Airborne Dust From Tailings Beaches

In this study, plenty of water was available to maintain a water cover over the tailings. This appreciably reduces the amount of dust released from the tailings ponds and is up to 99+% effective. The remaining particles that wash up onto the beach can be periodically sprayed to tie them down or washed back into the pond. If treatments are administered at the right times, up to 95% of dust released from this source will be eliminated; however, the costs may become prohibitive as 100% effectiveness is approached.

5.2.5 Mine Water Control

The effectiveness estimates for mine water control were taken from uranium mine data.⁽¹⁾ The estimates are as follows:

<u>Method</u>	<u>Effectiveness</u>
Settling Pond	30 to 90% of solids will settle out.
Add Flocculation and Clarification	TSS are reduced by 97%, COD is reduced by 86%, and radium is reduced by up to 99%.
Add Ion Exchanger	Recovers up to 92% of thorium.
Add Barium Chloride Coprecipitation	Radium is reduced up to 99.9%.
Add Lime Neutralization	Precipitates heavy metals, increases pH, and helps remove up to 90% of radium.

5.2.6 Control of Tailings Pond Seepage

The effectiveness of various methods of depositing the tailings to control seepage are estimated in Table 5.7. The base technology in this study is the use of a clay-core dam for a tailings pond in lieu of the more traditional dams constructed out of tailings. This should reduce seepage by up to a factor of five. The effectiveness of adding a 3-ft clay liner to the pond bottom should reduce seepage by another factor of 5 to 10. All of the remaining methods should essentially reduce seepage to zero, providing the liners are protected from breach by climatic effects, rodents, vehicular and animal traffic, etc. (The figures for effectiveness are best engineering judgements based upon very little available data and represent relative approximations only.)

5.2.7 Tailings Covers (at Decommissioning)

It will be necessary to cover the tailings in landfill pits or evaporated tailings ponds to tie down radioactive dust, reduce radioactivity levels at the surface, and reduce the emanation of thoron gas to the atmosphere.

TABLE 5.7. Estimated Effectiveness of Various Methods of Seepage Control

Method	Effectiveness
Clay-core dam without a lining (base)	0 to 15% Seepage
Clay-core dam with a 3-ft clay liner	0 to 3% Seepage
Clay-core dam with a 2-in. asphalt liner	0 to 1% Seepage
Clay-core dam with a 60-mil rubber ^(a) liner	0 to 0.2% Seepage
Dewater tailings and convey to clay-lined landfill	0 to 0.10% Seepage ^(b)
Dewater tailings, blend with 10% cement, and pump to a clay-lined landfill	0 to 0.08% Seepage ^(b)
Dewater tailings, blend with 40% asphalt, and truck to an unlined landfill	0 to 0.06% Seepage ^(b)

(a) Multi-ply Hypalon or equivalent.

(b) Includes allowance for rubber-lined recycle water storage pond also. However, this pond will not contain as large an amount of radionuclides and it will be spread over a smaller area.

The thickness requirements for covers over thorium mill tailings will not be as great as for uranium mill tailings because the radioactivity levels will decay substantially after 50 yr. Also, ^{220}Ra (thoron) requires about $1/6000^{\text{th}}$ the thickness of ^{222}Ra for an equivalent reduction of radon emanation to the environment, due to thoron's shorter half-life (e.g., for the same gas volume, pressure, and temperature, 1 ft of soil is as effective for reducing ^{220}Ra emanation as 6000 ft of soil is for ^{222}Ra emanation). Therefore, the covers assumed for the tailings in this study are probably excessively thick.

The effectiveness of earth, clay, and other covers will vary from site-to-site. Past studies^(2,5) of uranium tailings covers estimated the relative effectiveness of various materials for the cover as:

<u>Cover</u>	<u>Fraction of Radon Emitted(a)</u>
No Cover (Base)	1
1 ft of Earth	0.7
6 ft of Earth	0.09
10 ft of Earth	0.02
60 ft of Earth	0.003
1 in. of Asphalt	0.003
60 mil of Rubber (Hypalon or Equiv.)	0.003

(a) Based upon ^{222}Ra data for uranium tailings.
Values should be much lower for ^{220}Ra .

5.2.8 Refinery Waste Sludge

It was assumed that if the waste sludge were not shipped to offsite burial grounds, it would be disposed of in onsite landfills well above the groundwater table. The effectiveness against seepage was estimated as follows:

<u>Method</u>	<u>Effectiveness</u>
Truck to clay-lined landfill	0 to 0.4% seepage
Blend with asphalt and truck to landfill	0% seepage
Ship to approved burial site	0% seepage

5.3 REFERENCES

1. Environmental Protection Agency, Group II, Development Document for Interim Final and Proposed Effluent Limitation Guidelines and New Source Performance Standards for the Ore Mining and Dressing Industry, EPA 440/1-75061, U.S. Environmental Protection Agency, Washington, DC. October 1975.

2. M. B. Sears et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low as Practicable" Guides - Milling of Uranium Ores, ORNL-TM-4903, Vol. 1, Oak Ridge National Laboratory, Oak Ridge, TN, May 1975.
3. Belga G. Liptak, Environmental Engineers Handbook: Air Pollution, Vol. 2, Chilton Book Company, Radnor, Pennsylvania, 19089 1974.
4. Engineering-Science, Inc., Field Surveillance and Enforcement Guide for Primary Metallurgical Industries, PB-230, 898, prepared for Environmental Protection Agency by Engineering-Science, Inc., National Technical Information Service, Springfield, VA. 22161, December 1973.
5. U.S. Nuclear Regulatory Commission, Operation of Bear Creek Project Rocky Mountain Energy Company, Docket No. 40-8452, PB-267 375, National Technical Information Service, Springfield, VA. 22161, June 1977.

APPENDIX A
SITE-SPECIFIC DATA

TABLE A.1. Site-Specific Data(a)

Mine		Stock-Piled Sludge	Lemhi Pass	Hall Mountain	Wet Mountain
Type		--	Underground	Underground	Underground
Mineral		--	Thorite	Thorite	Thorite
Average Grade, %		--	0.356	1.1	0.96
ThO ₂ Reserves, tons		--	67,700	5,210	66,900
Production, tons/day		--	1,000	400	350
hr/day x day/yr		--	16x250	16x250	16x250
Dust Generated					
Wastes	- lb/hr	--	156.16	62.50	54.69
	- Ci/hr	--	2.55x10 ⁻⁴	3.158x10 ⁻⁴	2.41x10 ⁻⁴
Liquid Generated					
Wastes	- lb/hr	--	250,000	125,000	125,000
	- gpm	--	500	250	250
	- Ci/hr	--	1.43x10 ⁻³	7.2x10 ⁻⁴	7.2x10 ⁻⁴
Solid Generated					
Wastes	- lb/hr	--	1,875	750	656.25
<u>Mill/Refinery</u>					
Ore in, tons/day		6.6	1,000	400	350
Concentrate, tons/day		1.58	3.28	4.045	3.0888
hr/day x day/yr		22x308	22x250	22x250	22x250
Dust Generated					
Wastes	- lb/hr	144.64	900.77	294.14	120.8
	- Ci/hr	2.63x10 ⁻⁴	1.92x10 ⁻⁵	2.418x10 ⁻⁵	1.786x10 ⁻⁵
Liquid Generated					
Wastes	- lb/hr	5,859.4	527,520	217,660	184,480
	- gpm	11.72	801.45	364.95	280.4
	- Ci/hr	6.47x10 ⁻²	1.229x10 ⁻¹	1.5159x10 ⁻¹	1.58x10 ⁻¹
Solid Generated					
Wastes	- lb/hr	698	--	--	--
	- Ci/hr	1.59x10 ⁻³	--	--	--

(a) Excess significant figures are shown for some numbers and were used for computational purposes only.

TABLE A.1. (contd)

<u>Mine</u>	<u>Palmer, MI</u>	<u>Bald Mountain</u>	<u>Conway Granite</u>
Type	Open-pit	Open-pit	Open-pit
Mineral	Conglomerate	Conglomerate	Granite
Average Grade, %	0.06	0.00951	0.006
ThO ₂ Reserves, tons	193,000	2,600	35,000,000
Production, tons/day	41,700	10,000	100,000
hr/day x day/yr	24x240	24x240	24x350
Dust Generated Wastes - lb/hr	4,340	1,042	10,420
- Ci/hr	1.36×10^{-3}	5.183×10^{-5}	5.743×10^{-4}
Liquid Generated Wastes - lb/hr	750,000	500,000	1,000,000
- gpm	1,500	1,000	2,000
- Ci/hr	3.931×10^{-4}	2.613×10^{-4}	9.2345×10^{-4}
Solid Generated Wastes - lb/hr	1,041,600	250,000	1,666,000
<u>Mill</u>			
Ore in, tons/day	30,300/ 41,700	7,272.76/ 10,000	100,000
Concentrate, tons/day	209.11	7.404	6.32
hr/day x day/yr	22x330/240	22x330/240	22x350
Dust Generated Wastes - lb/hr	5,237.2	252.435	454.53
- Ci/hr	1.625×10^{-4}	5.92×10^{-6}	2.119×10^{-5}
Liquid Generated Wastes - lb/hr	1,800,760	433,444	133,420
- gpm	3,116	866.9	267
- Ci/hr	3.65×10^{-2}	1.26×10^{-3}	2.3418×10^{-2}
Solid Generated Wastes - lb/hr	3,115,000	750,520	11,598,920
- Ci/hr	3.01×10^{-1}	1.16×10^{-2}	1.64×10^{-1}
<u>Refinery</u>			
Concentrate in, tons/day	209.11	7.37	6.27
Output, tons/day	10.65	0.403	3.43
By-product, tons/day	235.4	33.22	2,797
hr/day x day/yr	22x330	22x330	22x350
Dust Generated Wastes - lb/hr	7,619	204.27	313.1
- Ci/hr	1.24×10^{-4}	4.59×10^{-6}	5.7172×10^{-4}
Liquid Generated Wastes - lb/hr	510,180	10,108	9,812.5
- gpm	816.72	20.216	19.625
- Ci/hr	4.3656	1.645×10^{-2}	2.61×10^{-1}
Solid Generated Wastes - lb/hr	--	--	663
- Ci/hr	--	--	6.76×10^{-3}

APPENDIX B
RADIOLOGICAL DATA

APPENDIX B
RADIOLOGICAL DATA^(a)

B.1 SPECIFIC ACTIVITIES

The specific activities of ^{232}Th , ^{238}U , and ^{235}U can be calculated on a Ci/lb basis as follows:

$$\text{Specific Activity} = \text{SA} = \lambda N$$

where λ = the decay constant for a particular radioactive element

N = number of atoms per gram

$$\lambda = 0.693/T_{1/2}$$

$T_{1/2}$ = the half-life of the element in seconds.

$$\text{So SA} = \frac{(0.693)N}{T_{1/2}} = \text{discharge/sec/g}$$

$$\text{or SA} = \frac{(0.693)N}{T_{1/2} (3.7 \times 10^{10})} = \frac{(1.87297 \times 10^{-11})N}{T_{1/2}} = \text{Ci/g}$$

For ^{232}Th the following specific activity can be derived:

$$\text{SA} = \frac{(1.87297 \times 10^{-11})(454 \text{ g/lb})(0.6023 \times 10^{24} \text{ atom/m})}{(232.0382 \text{ g/m})(1.40 \times 10^{10} \text{ yr})(3.1536 \times 10^7 \text{ sec/yr})}$$

$$\text{SA} = 4.99926 \times 10^{-5} \text{ Ci/lb}$$

For ^{235}U , $\text{SA} = 9.731646 \times 10^{-4} \text{ Ci/lb}$, and for ^{238}U , $\text{SA} = 1.51268 \times 10^{-4} \text{ Ci/lb}$.

The ^{232}Th decay series is composed of nine daughter products, as shown in Figure B.1. These nine products have approximately nine times the activity of ^{232}Th itself. Thus, when given the specific activity of ^{232}Th , we can estimate the total specific activity as being ten times as much. This was done for thorium in Appendices C and D.

(a) Excess significant figures are shown for some numbers and were used for computational purposes only.

FIGURE B.1. Thorium Decay Series

FIGURE B.2. ^{238}U Decay Series

FIGURE B.3. ^{235}U Decay Series

Figures B.2 and B.3 show the decay series for ^{238}U and ^{235}U , respectively. As shown, there are thirteen ^{238}U daughters and ten ^{235}U daughters. As with ^{232}Th , the daughter products contribute 13 and 10 times the specific activity of ^{238}U and ^{235}U , respectively.

B.2 MAXIMUM PERMISSIBLE CONCENTRATION (MPC) AND RELATIVE RADIOTOXICITY

The data for this part of the appendix is taken from the CRC Handbook of Radioactive Nuclides.⁽¹⁾ The standards for maximum permissible concentrations (MPCs) used in this reference are based on Appendix B of the U.S. Atomic Energy Commission's publication 10 CFR 20. The pertinent isotopes and their MPCs in air and water are shown in Table B.1. The MPCs shown are the limiting average concentrations in air and water that an employee may be exposed to 40 hours per week during a lifetime of employment. As seen for air, ^{232}Th and natural thorium have an MPC level of $3 \times 10^{-11} \mu\text{Ci/ml}$, which is less than that of uranium in any form. The same is also true for the MPC of soluble thorium in water ($3 \times 10^{-5} \mu\text{Ci/ml}$). For this reason the standards used to evaluate the environmental control technologies were the natural thorium MPCs.

One of the reasons that the standards for thorium are stricter than for uranium is due to the relative radiotoxicity. As shown in Table B.2, ^{232}Th and natural thorium deliver 15 rems of radiation to the critical organ or the lung with much fewer curies than do ^{235}U , ^{238}U , or natural uranium. Thus, thorium is more dangerous than uranium from this point of view and the standards, as shown in Table B.1, are stricter.

B.3 REFERENCES

1. Yen Wang (ed.), Handbook of Radioactive Nuclides, The Chemical Rubber Company, Cleveland, OH, 1969.

**TABLE B.1. Maximum Permissible Concentration of Radionuclides
in Air and Water**

Isotope		MPC in Air, $\mu\text{Ci/ml}$	MPC in Water, $\mu\text{Ci/ml}$
Natural Thorium	Soluble	3×10^{-11}	3×10^{-5}
	Insoluble	3×10^{-11}	3×10^{-4}
^{232}Th	Soluble	3×10^{-11}	5×10^{-5}
	Insoluble	3×10^{-11}	1×10^{-3}
^{228}Th	Soluble	9×10^{-12}	2×10^{-4}
	Insoluble	6×10^{-12}	4×10^{-4}
^{228}Ra	Soluble	7×10^{-11}	8×10^{-7}
	Insoluble	4×10^{-11}	7×10^{-4}
^{228}Ac	Soluble	8×10^{-8}	3×10^{-3}
	Insoluble	2×10^{-8}	3×10^{-3}
^{224}Ra	Soluble	5×10^{-9}	7×10^{-5}
	Insoluble	7×10^{-10}	2×10^{-4}
^{220}Rn	Soluble	3×10^{-7}	--
^{212}Pb	Soluble	2×10^{-8}	6×10^{-4}
	Insoluble	2×10^{-8}	5×10^{-4}
^{212}Bi	Soluble	1×10^{-7}	1×10^{-2}
	Insoluble	2×10^{-7}	1×10^{-2}
^{238}U	Soluble	7×10^{-11}	1×10^{-3}
	Insoluble	1×10^{-10}	1×10^{-3}
^{235}U	Soluble	5×10^{-10}	8×10^{-4}
	Insoluble	1×10^{-10}	8×10^{-4}
Natural Uranium	Soluble	7×10^{-11}	5×10^{-4}
	Insoluble	6×10^{-11}	5×10^{-4}
^{230}Th	Soluble	2×10^{-12}	5×10^{-5}
	Insoluble	1×10^{-11}	9×10^{-4}
^{226}Ra	Soluble	3×10^{-11}	4×10^{-7}
	Insoluble	5×10^{-11}	9×10^{-4}
^{222}Rn	Soluble	1×10^{-7}	--
^{210}Pb	Soluble	1×10^{-10}	4×10^{-6}
	Insoluble	2×10^{-10}	5×10^{-3}
^{231}Pa	Soluble	1×10^{-12}	3×10^{-5}
	Insoluble	1×10^{-10}	8×10^{-4}
^{227}Ac	Soluble	2×10^{-12}	6×10^{-5}
	Insoluble	3×10^{-11}	9×10^{-3}

TABLE B.2. Relative Radiotoxicity of Radionuclides

<u>Isotope</u>	<u>Single Inhalation, in Curies, to Give 15 rem to Critical Organ, Ci/15 rem</u>	<u>Single Inhalation, in Curies, to Give 15 rem to Lung, Ci/15 rem</u>
^{232}Th + Natural Thorium	2.25×10^{-9}	2.60×10^{-8}
^{238}U + Natural Uranium	1.90×10^{-7}	3.00×10^{-7}
^{235}U (+1% ^{234}U)	1.10×10^{-6}	2.60×10^{-7}
^{226}Ra	4.90×10^{-8}	1.50×10^{-8}
^{210}Pb	3.20×10^{-7}	5.30×10^{-7}
^{227}Ac	3.00×10^{-9}	6.9×10^{-8}

APPENDIX C
MINE EFFLUENTS

APPENDIX C
MINE, GENERATED WASTES^(a)

C.1 LEMHI PASS MINE

Airborne Generated Wastes

The dust level = 0.1% to 0.15% of the ore mined. Only 25% of this dust is in the mine or controllable, the other 75% is generated by the loading and transportation operations. It is assumed that 0.125% of the ore mined becomes dust. This mine is a 1000 ton/day ore mine with an average grade of 0.356% ThO_2 .

Controlled Dust

The amounts and concentrations for the controlled dust in the mine are:

$$\begin{aligned}\text{Mine dust} &= (0.00125)(0.25)(1000 \text{ tons/day})(1 \text{ day}/16 \text{ hr})(2000 \text{ lb/ton}) \\ &= 39.0 \text{ lb/hr}\end{aligned}$$

$$\text{ThO}_2 = (0.00356)(39.0) = 0.13884 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(0.13884) = 0.12218 \text{ lb/hr}$$

$$\text{U} = (0.01)(0.12218) = 1.222 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(8.145 \times 10^{-3}) = 1.21 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 1.2 \times 10^{-5} \text{ lb/hr}$$

The activity in the mine dust is:

^{232}Th	0.12218 lb/hr	$6.108 \times 10^{-6} \text{ Ci/hr}$
^{238}U	$1.21 \times 10^{-3} \text{ lb/hr}$	$1.83 \times 10^{-7} \text{ Ci/hr}$
^{235}U	$1.2 \times 10^{-5} \text{ lb/hr}$	$1.17 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$5.50 \times 10^{-5} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$2.38 \times 10^{-6} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$1.17 \times 10^{-7} \text{ Ci/hr}$

This dust load is to be controlled with a ventilating system with a capacity of 300,000 ft^3/min . The working areas will also be kept wet down to control the dust level.

(a) Excess significant figures are shown for some numbers and were used for computational purposes only.

Uncontrolled Dust

The amounts and concentrations for uncontrolled dust in the mine are:

$$\begin{aligned}\text{Uncontrolled dust} &= (0.75)(0.00125)(1000 \text{ tons/day})(1 \text{ day}/16 \text{ hr}) \\ &\quad (2000 \text{ lb/ton}) = 117.15 \text{ lb/hr}\end{aligned}$$

$$\text{Th} = (0.88)(0.00356)(117.15) = 0.367 \text{ lb/hr}$$

$$\text{U} = (0.01)(0.367) = 3.67 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(3.67 \times 10^{-3}) = 3.64 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 3.0 \times 10^{-5} \text{ lb/hr}$$

The activity in the uncontrolled dust is:

^{232}Th	0.367 lb/hr	$1.83 \times 10^{-5} \text{ Ci/hr}$
^{238}U	$3.64 \times 10^{-3} \text{ lb/hr}$	$5.51 \times 10^{-7} \text{ Ci/hr}$
^{235}U	$3.0 \times 10^{-5} \text{ lb/hr}$	$2.92 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.65 \times 10^{-4} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$7.16 \times 10^{-6} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$2.92 \times 10^{-7} \text{ Ci/hr}$

To control this dust, it may be possible to wet the major points of dust release and erect barriers. The values given above are dependent on many factors; some of which are the wind conditions, rainfall, travel distance, etc.

Liquid Wastes

Lemhi Pass could be classified as an intermediate (500 to 2000 gpm) or dry (500 gpm) mine in terms of liquid output. If 500 gpm is assumed as an average figure, the next question is what concentration of ThO_2 to assume. In uranium mines, the concentration of ^{238}U ranges from 5 to 20 ppm. If it is assumed that ThO_2 behaves similarly, then the average ThO_2 concentration is 12.5 ppm or 12.5 mg/ ; so the amount of:

$$\text{ThO}_2 = \frac{12.5 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{500 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 3.13 \text{ lb/hr}$$

$$^{232}\text{Th} = 2.75 \text{ lb/hr}$$

$$\text{U} = (0.01)(2.75) = 2.75 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(2.75 \times 10^{-2}) = 2.74 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 1.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the water is:

^{232}Th	2.75 lb/hr	$1.37 \times 10^{-4} \text{ Ci/hr}$
^{238}U	$2.74 \times 10^{-2} \text{ lb/hr}$	$4.14 \times 10^{-6} \text{ Ci/hr}$
^{235}U	$1.0 \times 10^{-4} \text{ lb/hr}$	$9.73 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.23 \times 10^{-3} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$5.39 \times 10^{-5} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$9.73 \times 10^{-7} \text{ Ci/hr}$

Settling ponds are necessary to collect and treat this stream. Various chemicals may have to be added to settle and clean these fluids.

Solids

The solid wastes consist of the wall rock and gangue material of too low a grade to be considered ore. The ratio of waste to ore is 30 lb waste rock/ton ore. The waste rock obtained is used onsite and has a low concentration of radioactive substances. Therefore, the external environment is not harmed appreciably. Lemhi Pass waste rock from one 1000-ton/day ore mine is 15 tons/day of waste rock. All underground mines are similar to the Lemhi Pass mine in terms of solid waste generated.

C.2 HALL MOUNTAIN MINE

Airborne Generated Wastes

The same assumptions apply here as were used for the Lemhi Pass mine. The Hall Mountain mine is a 400-ton/day underground mine with an average ore grade of 1.1% ThO_2 .

Controlled Dust

The amounts and concentrations for the controlled dust in the mine are:

$$\begin{aligned}\text{Mine dust} &= (0.00125)(0.25)(400 \text{ tons/day})(1 \text{ day}/16 \text{ hr})(2000 \text{ lb/ton}) \\ &= 15.625 \text{ lb/hr}\end{aligned}$$

$$^{232}\text{Th} = (0.88)(0.011)(15.625) = 0.15125 \text{ lb/hr}$$

$$\text{U} = (0.01)(0.151) = 1.51 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.51 \times 10^{-3}) = 1.51 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 1.1 \times 10^{-5} \text{ lb/hr}$$

The activity in the mine dust is:

^{232}Th	0.151 lb/hr	7.55×10^{-6} Ci/hr
^{238}U	1.499×10^{-3} lb/hr	2.27×10^{-7} Ci/hr
^{235}U	1.1×10^{-5} lb/hr	1.07×10^{-8} Ci/hr
^{232}Th Daughters (9)	Trace	6.80×10^{-5} Ci/hr
^{238}U Daughters (13)	Trace	2.95×10^{-6} Ci/hr
^{235}U Daughters (10)	Trace	1.07×10^{-7} Ci/hr

The capacity of the ventilating system will be about 160,000 ft³/min. The working areas will be kept wet down to minimize dust levels in the mine.

Uncontrolled Dust

The amounts and concentrations of uncontrolled dust in the mine are:

$$\begin{aligned}\text{Uncontrolled dust} &= (0.75)(0.00125)(400 \text{ tons/day})(1 \text{ day}/16 \text{ hr}) \\ &\quad (2000/\text{lb/ton}) = 46.875 \text{ lb/hr}\end{aligned}$$

$$^{232}\text{Th in dust} = (0.88)(0.011)(46.875) = 0.45375 \text{ lb/hr}$$

$$\text{U in dust} = (0.01)(0.45375) = 4.5375 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U in dust} = (0.993)(4.5375 \times 10^{-3}) = 4.5057 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U in dust} = 3.18 \times 10^{-5} \text{ lb/hr}$$

The activity in the uncontrolled dust is:

^{232}Th	0.45375 lb/hr	2.27×10^{-5} Ci/hr
^{238}U	4.5057×10^{-3} lb/hr	6.82×10^{-7} Ci/hr
^{235}U	3.18×10^{-5} lb/hr	3.09×10^{-8} Ci/hr
^{232}Th Daughters (9)	Trace	2.04×10^{-4} Ci/hr
^{238}U Daughters (13)	Trace	8.86×10^{-6} Ci/hr
^{235}U Daughters (10)	Trace	3.09×10^{-7} Ci/hr

The best ways to minimize this condition may be to wet the dust release points and erect wind barriers.

Liquid Wastes

The Hall Mountain mine is about half as large as a Lemhi Pass mine, so a value of 250 gpm for liquid release will be used. The concentration to be used, 12.5 ppm ThO_2 , would also be similar. The amounts released are:

$$\text{ThO}_2 = \frac{12.5 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{250 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 1.565 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(1.565) = 1.38 \text{ lb/hr}$$

$$\text{U} = 1.38 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.38 \times 10^{-2}) = 1.37 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 1.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the water is:

^{232}Th	1.38 lb/hr	6.90×10^{-5} Ci/hr
^{238}U	1.37×10^{-2} lb/hr	2.07×10^{-6} Ci/hr
^{235}U	1.0×10^{-4} lb/hr	9.73×10^{-8} Ci/hr
^{232}Th Daughters (9)	Trace	6.21×10^{-4} Ci/hr
^{238}U Daughters (13)	Trace	2.69×10^{-5} Ci/hr
^{235}U Daughters (10)	Trace	9.73×10^{-7} Ci/hr

A settling pond will be needed to collect these wastes. Various treatment processes may be used to clean this water.

Solids

There will be 6 tons/day of waste rock from the Hall Mountain mine. The waste rock will be used on site and has a low concentration of radioactive substances. This small amount will not appreciably harm the environment.

C.3 WET MOUNTAIN MINE

Airborne Generated Wastes

The assumptions used for the Lemhi Pass mine also apply here. The Wet Mountain mine is a 350-ton/day underground mine with an average ore grade of 0.96% ThO₂.

Controlled Dust

The amounts for the controlled dust in the mine are:

$$\begin{aligned}\text{Mine dust} &= (0.00125)(0.25)(350 \text{ tons/day})(1 \text{ day}/16 \text{ hr})(2000 \text{ lb/ton}) \\ &= 13.67 \text{ lb/hr}\end{aligned}$$

$$^{232}\text{Th} = (0.88)(0.0096)(13.67) = 1.155 \times 10^{-1} \text{ lb/hr}$$

$$\text{U} = (0.01)(0.155 \times 10^{-1}) = 1.155 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.55 \times 10^{-3}) = 1.1469 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 8.1 \times 10^{-6} \text{ lb/hr}$$

The activity in the mine dust is:

²³² Th	$1.155 \times 10^{-1} \text{ lb/hr}$	$5.77 \times 10^{-6} \text{ Ci/hr}$
²³⁸ U	$1.1469 \times 10^{-3} \text{ lb/hr}$	$1.73 \times 10^{-7} \text{ Ci/hr}$
²³⁵ U	$8.1 \times 10^{-6} \text{ lb/hr}$	$7.88 \times 10^{-9} \text{ Ci/hr}$
²³² Th Daughters (9)	Trace	$5.19 \times 10^{-5} \text{ Ci/hr}$
²³⁸ U Daughters (13)	Trace	$2.26 \times 10^{-6} \text{ Ci/hr}$
²³⁵ U Daughters (10)	Trace	$7.88 \times 10^{-8} \text{ Ci/hr}$

The capacity of the ventilating system will be about 140,000 ft³/min. The dust level will be minimized considerably by keeping the working areas wet.

Uncontrolled Dust

The amounts for uncontrolled dust in the mine are:

$$\text{Uncontrolled dust} = (0.75)(0.00125)(350 \text{ tons/day})(1 \text{ day/16 hr}) \\ (2000 \text{ lb/ton}) = 41.02 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(0.0096)(41.02) = 0.3465 \text{ lb/hr}$$

$$\text{U} = (0.01)(0.3465) = 3.456 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(3.465 \times 10^{-3}) = 3.44 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 2.5 \times 10^{-5} \text{ lb/hr}$$

The activity in the uncontrolled dust is:

^{232}Th	0.3465 lb/hr	$1.73 \times 10^{-5} \text{ Ci/hr}$
^{238}U	$3.44 \times 10^{-3} \text{ lb/hr}$	$5.20 \times 10^{-7} \text{ Ci/hr}$
^{235}U	$2.5 \times 10^{-5} \text{ lb/hr}$	$2.43 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.56 \times 10^{-4} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$6.76 \times 10^{-6} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$2.43 \times 10^{-7} \text{ Ci/hr}$

The best ways to minimize this dust load are to wet down the work areas and erect barriers around the mine and loading zone.

Liquid Wastes

The Wet Mountain mine is about half as large as the Lemhi Pass mine; so a value of 250 gpm for liquid release was used. The concentration was also similar, 12.5 ppm ThO_2 . The amounts released are:

$$\text{ThO}_2 = \frac{12.5 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{250 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 1.565 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(1.565) = 1.38 \text{ lb/hr}$$

$$\text{U} = 1.38 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.38 \times 10^{-2}) = 1.37 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 1.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the water is the same as that for the Hall Mountain mine. As previously mentioned, a settling pond will be needed.

Solids

There are 5.25 tons/day of waste rock from the Wet Mountain mine. The waste rock will be used on site and has a low concentration of radioactive substances. This small amount will not appreciably harm the environment.

C.4 PALMER, MICHIGAN, MINE

Airborne Generated Wastes

The airborne release factors range from 0.1% to 0.15% of the ore mined. The assumed value is 0.125%. The amounts for the dust released are:

$$\text{Dust} = (0.00125)(10,000,000 \text{ tons/yr})(1 \text{ yr}/240 \text{ days})(1 \text{ day}/24 \text{ hr}) \\ (2000 \text{ lb/ton}) = 4340 \text{ lb/hr}$$

$$\text{ThO}_2 = (0.0006)(4340) = 2.60 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(2.60) = 2.29 \text{ lb/hr}$$

$$\text{U} = (0.0435)(2.29) = 9.96 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(9.96 \times 10^{-2}) = 9.89 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 7.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the mine dust is:

^{232}Th	2.29 lb/hr	$1.14 \times 10^{-4} \text{ Ci/hr}$
^{238}U	$9.89 \times 10^{-2} \text{ lb/hr}$	$1.50 \times 10^{-5} \text{ Ci/hr}$
^{235}U	$7.0 \times 10^{-4} \text{ lb/hr}$	$6.8 \times 10^{-7} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.03 \times 10^{-3} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$1.94 \times 10^{-4} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$6.81 \times 10^{-6} \text{ Ci/hr}$

The dust level will be minimized by wetting down the mining area and the roads and by erecting barriers. Other than that, only proper methods of ore blasting and handling will lower the dust level.

Liquid Wastes

A large portion of the waste water will be from precipitation. The concentration in the ore removed is only 0.06%, so the amount in the groundwater removed is probably less than 1 ppm. All of the surface mines studied will be based on 1 ppm ThO_2 . A mine in the same area as the conceptual thorium oxide mine removes an average of 1500 gpm. The amounts released in the liquid wastes are:

$$\text{ThO}_2 = \frac{1 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{1500 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 0.75 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(0.75) = 0.66 \text{ lb/hr}$$

$$\text{U} = (0.0435)(0.66) = 0.029 \text{ lb/hr}$$

$$^{238}\text{U} = (0.029)(0.993) = 0.0288 \text{ lb/hr}$$

$$^{235}\text{U} = 2.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the water is:

^{232}Th	0.66 lb/hr	$3.3 \times 10^{-5} \text{ Ci/hr}$
^{238}U	0.0288 lb/hr	$4.36 \times 10^{-6} \text{ Ci/hr}$
^{235}U	$2.0 \times 10^{-4} \text{ lb/hr}$	$1.95 \times 10^{-7} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$2.97 \times 10^{-4} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$5.66 \times 10^{-5} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$1.95 \times 10^{-6} \text{ Ci/hr}$

If the mill is located near the mine, this water stream may be used in the mill circuit. Holding ponds may be needed to allow the solids to precipitate.

Solids

The solid waste consists of overburden and waste rock from mining. This waste rock will be stored onsite, either in the pit itself or adjacent to it; therefore, no external environmental effects will take place. Because of the low concentration of ThO_2 in the ore and the fact that the waste rock has even a lower concentration of ThO_2 , the radioactive effects will be minimal.

C.5 BALD MOUNTAIN MINE

Airborne Generated Wastes

The amounts of airborne wastes released in the mine are:

$$\begin{aligned}\text{Dust} &= (0.00125)(10,000 \text{ tons/day})(1 \text{ day}/24 \text{ hr})(2000 \text{ lb/ton}) \\ &= 1042 \text{ lb/hr}\end{aligned}$$

$$\text{ThO}_2 = (0.0000951)(1042) = 9.9 \times 10^{-2} \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(9.9 \times 10^{-2}) = 8.71 \times 10^{-2} \text{ lb/hr}$$

$$\text{U} = (0.0435)(8.71 \times 10^{-2}) = 3.79 \times 10^{-3} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(3.79 \times 10^{-3}) = 3.76 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 3.0 \times 10^{-5} \text{ lb/hr}$$

The activity in the mine dust is:

^{232}Th	$8.71 \times 10^{-2} \text{ lb/hr}$	$4.35 \times 10^{-6} \text{ Ci/hr}$
^{238}U	$3.76 \times 10^{-3} \text{ lb/hr}$	$5.69 \times 10^{-7} \text{ Ci/hr}$
^{235}U	$3.0 \times 10^{-5} \text{ lb/hr}$	$2.92 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$3.92 \times 10^{-5} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$7.39 \times 10^{-6} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$2.92 \times 10^{-7} \text{ Ci/hr}$

As mentioned for the Palmer, Michigan, mine, the best ways to minimize the dust levels are to wet down the working and transportation areas and erect wind barriers.

Liquid Wastes

It is assumed that the maximum concentration of ThO_2 in the water is 1 ppm and that the flow rate is 1000 gpm. There will be less precipitation here than in Palmer, Michigan, and the mine is also smaller. The amounts released in the liquid wastes are:

$$\text{ThO}_2 = \frac{1 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{1000 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 0.50 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(0.50) = 0.44 \text{ lb/hr}$$

$$\text{U} = (0.0435)(0.44) = 1.91 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.91 \times 10^{-2}) = 1.90 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 1.0 \times 10^{-4} \text{ lb/hr}$$

The activity in the water is:

^{232}Th	0.44 lb/hr	$2.2 \times 10^{-5} \text{ Ci/hr}$
^{238}U	$1.9 \times 10^{-2} \text{ lb/hr}$	$2.87 \times 10^{-6} \text{ Ci/hr}$
^{235}U	$1.0 \times 10^{-4} \text{ lb/hr}$	$9.73 \times 10^{-8} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.98 \times 10^{-4} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$3.74 \times 10^{-5} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$9.73 \times 10^{-7} \text{ Ci/hr}$

Holding ponds or evaporation ponds will be needed to contain and treat this waste stream. If the mill is located nearby, some water may be used in it.

Solids

The waste rock and overburden will be stored onsite or adjacent to the mine. Because of this and the low concentration of radioactive substances, there should be no external environmental effects.

C.6 CONWAY GRANITE MINE

Airborne Generated Wastes

The amounts of airborne wastes released from the mine are:

$$\begin{aligned} \text{Dust} &= (0.00125)(100,000 \text{ tons/day})(1 \text{ day}/24 \text{ hr})(2000 \text{ lb/ton}) \\ &= 10,420 \text{ lb/hr} \end{aligned}$$

$$\text{ThO}_2 = (0.00006)(10,420) = 0.625 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(0.625) = 0.55 \text{ lb/hr}$$

$$\text{U} = (0.25)(0.55) = 0.1375 \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(0.1375) = 0.1365 \text{ lb/hr}$$

$$^{235}\text{U} = 1.0 \times 10^{-3} \text{ lb/hr}$$

The activity in the mine dust is:

^{232}Th	0.55 lb/hr	2.75×10^{-5} Ci/hr
^{238}U	0.1365 lb/hr	2.06×10^{-5} Ci/hr
^{235}U	1.0×10^{-3} lb/hr	9.73×10^{-7} Ci/hr
^{232}Th Daughters (9)	Trace	2.475×10^{-4} Ci/hr
^{238}U Daughters (13)	Trace	2.68×10^{-4} Ci/hr
^{235}U Daughters (10)	Trace	9.73×10^{-6} Ci/hr

As previously mentioned, the best ways to minimize the dust levels are to wet down the working and transportation areas and erect wind barriers.

Liquid Wastes

It was assumed that 1 ppm is the maximum concentration of ThO_2 in the water and that the flow rate is 2000 gpm. The large flow rate is due to the large area to be mined and the fact that the mine is in an area with high precipitation levels. The amounts released in the liquid wastes are:

$$\text{ThO}_2 = \frac{1 \text{ mg}}{\ell} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{2000 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{3.79 \ell}{\text{gal}} = 1.00 \text{ lb/hr}$$

$$^{232}\text{Th} = (0.88)(1.0) = 0.88 \text{ lb/hr}$$

$$\text{U} = (0.25)(0.88) = 0.22 \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(0.22) = 0.218 \text{ lb/hr}$$

$$^{235}\text{U} = 2.0 \times 10^{-3} \text{ lb/hr}$$

The activity in the water is:

^{232}Th	0.88 lb/hr	4.4×10^{-5} Ci/hr
^{238}U	0.218 lb/hr	3.3×10^{-5} Ci/hr
^{235}U	2.0×10^{-3} lb/hr	1.95×10^{-6} Ci/hr
^{232}Th Daughters (9)	Trace	3.96×10^{-4} Ci/hr
^{238}U Daughters (13)	Trace	4.29×10^{-4} Ci/hr
^{235}U Daughters (10)	Trace	1.95×10^{-5} Ci/hr

If the mill is located near the mine, this water can be used there. Holding or evaporation ponds may also be used to control or treat the liquid wastes.

Solids

The ratio of 2:10, waste rock to ore, applies at this mine. Thus, there are 20,000 tons/day of waste rock. This will be stored onsite, either in the mine itself or adjacent to it. Because of this and because of the low concentration of radioactive substances, there should be no external environmental effects.

APPENDIX D
MILL AND REFINERY GENERATED WASTES

APPENDIX D
MILL AND REFINERY GENERATED WASTES^(a)

D.1 GENERATED WASTES FROM STOCKPILE REFINERY

Waste Sludge

The sludge leaves the mill at a rate of 698 lb/hr, of which 80% is solids and 2.64 lb are ^{232}Th , as shown in Figure D.1. The amount of uranium in the entering sludge is 1% of the total or 6 lb. If the same ratio as assumed between Th and U in the waste sludge, there is 0.12 lb of uranium in the waste sludge. The uranium is split between ^{238}U and ^{235}U at a ratio of:

$$\left(\frac{0.993}{0.007}\right) \left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

Thus, there are 0.1192 lb/hr of ^{238}U and 0.0008 lb/hr of ^{235}U in the waste sludge. The activity in the waste sludge stream is:

^{232}Th	2.64 lb/hr	1.32×10^{-4} Ci/hr
^{238}U	0.1192 lb/hr	1.88×10^{-5} Ci/hr
^{235}U	0.0008 lb/hr	7.79×10^{-7} Ci/hr
^{232}Th Daughters (9)	Trace	1.188×10^{-3} Ci/hr
^{238}U Daughters (13)	Trace	2.444×10^{-4} Ci/hr
^{235}U Daughters (10)	Trace	7.79×10^{-6} Ci/hr

This waste sludge can be disposed of by proper burial techniques at an approved site.

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Extraction and Scrubbing Stream - 1321 lb/hr containing 0.264 lb/hr ^{232}Th with a total flow of 2.64 gpm.

Uranium Removal Stream - 1468 lb/hr with no ^{232}Th and a total flow of 2.94 gpm.

(a) Excess significant figures are shown for some numbers and were used for computational purposes only.

FIGURE D.1. Stockpile Refinery Flowsheet

FIGURE D.1. Legend: Flow Streams for Stockpile Refinery

1. 600 lb/hr sludge w/132 lb/hr ^{232}Th	19. 2324 lb/hr H_2O
2. 315 lb/hr HNO_3	20. 612 lb/hr w/129.096 lb/hr ^{232}Th
3. 517 lb/hr H_2O	21. 34 lb/hr HNO_3
4. 1432 lb/hr w/132 lb/hr ^{232}Th	22. 40 lb/hr H_2O
5. 698 lb/hr sludge w/2.64 lb/hr ^{232}Th
(80% solids)	23. 52 lb/hr oxalic acid
6. 734 lb/hr w/129.36 lb/hr ^{232}Th	24. 738 lb/hr w/129.096 lb/hr ^{232}Th
7. 587 lb/hr of 4N HNO_3	25. 133.4 lb/hr H_2O
8. 1321 lb/hr w/0.294 lb/hr ^{232}Th	26. 494.4 lb/hr w/1.056 lb/hr ^{232}Th
9. 2936 lb/hr	27. 143 lb/hr Na_2CO_3
10. 2936 lb/hr w/129.096 lb/hr ^{232}Th	28. 637.4 lb/hr w/1.056 lb/hr ^{232}Th
11. 2936 lb/hr of 0.1N HNO_3	29. 377 lb/hr w/128.04 lb/hr ^{232}Th
12. 587 lb/hr	30. 109 lb/hr H_2O
13. 3523 lb/hr	31. 268 lb/hr w/128.04 lb/hr ^{232}Th
14. 1468 lb/hr of Na_2CO_3 (5%)	32. 20 lb/hr O_2
15. 734 lb/hr of 4N HNO_3	33. 47 lb/hr H_2O and 95 lb/hr CO_2
w/2.64 lb/hr ^{232}Th
16. 1468 lb/hr	34. 2.614 lb/hr ^{232}Th
17. 734 lb/hr of HNO_3 to be used to
make No. 7 stream	35. 47 lb/hr H_2O and 95 lb/hr CO_2
w/0.026 lb/hr ^{232}Th
18. 2936 lb/hr w/129.096 lb/hr ^{232}Th	36. 144 lb/hr w/125.4 lb/hr ^{232}Th

Boildown and Evaporation Stream - 2324 lb/hr of mainly H₂O with a total flow of 4.65 gpm.

Plate-and-Frame-Press Stream - 637.4 lb/hr containing 1.056 lb/hr ²³²Th with a total flow of 1.27 gpm.

Twin Screw Dryer Stream - 190 lb/hr mainly H₂O with a total flow of 0.22 gpm.

A total of 5859.4 lb/hr flows to the tailings pond. It contains 1.32 lb/hr ²³²Th. The total flow to the pond is 11.72 gpm. All of uranium in the entering sludge goes to the tailings pond except the amount leaving in the waste sludge stream. The amounts of uranium in the pond are:

U in tailings pond = 6.0 - 0.12 = 5.88 lb/hr

²³⁸U = (0.993)(5.88) = 5.838 lb/hr

²³⁵U = (0.007)(5.88) = 0.042 lb/hr

The activity in the tailings pond is:

²³² Th	1.32 lb/hr	6.60×10^{-5} Ci/hr
²³⁸ U	5.838 lb/hr	8.83×10^{-4} Ci/hr
²³⁵ U	0.042 lb/hr	4.09×10^{-5} Ci/hr
²³² Th Daughters	Trace	5.18×10^{-2} Ci/hr
²³⁸ U Daughters (13)	Trace	1.1479×10^{-2} Ci/hr
²³⁵ U Daughters (10)	Trace	4.09×10^{-4} Ci/hr

Drying and Loading Dust

There are 47 lb/hr H₂O, 95 lb/hr CO₂, and 2.64 lb/hr of ²³²Th in the dust stream, see Figure D.1. This stream is controlled by hoods connected to a 6,000-cfm HEPA and baghouse filter system as shown. This system removes 99% of the ²³²Th dust. The solid from the system is recycled back into the packaging process. There are 2.61 lb/hr of ²³²Th solids. The other 0.026 lb/hr of ²³²Th is emitted to the atmosphere. The activity in the stream is:

²³² Th (solid)	2.61 lb/hr	1.30×10^{-4} Ci/hr
²³² Th (airborne)	0.026 lb/hr	1.30×10^{-6} Ci/hr
²²⁸ Th (solid)	Trace	1.30×10^{-4} Ci/hr
²²⁸ Th (air)	Trace	1.30×10^{-6} Ci/hr

D.2 GENERATED WASTES FROM LEMHI PASS THORITE MILL/REFINERY

Dust from Unloading, Crushing, and Grinding the Ore

From these processes, 4.55 lb/hr of ore are emitted in dust; of this, 0.0132 lb is ^{232}Th , as shown in Figure D.2. The uranium content of the dust = $(100/1)(\text{Th}/\text{U})$ so $(0.0132)(0.01) = 1.32 \times 10^{-4}$ lb U. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

There are 1.31×10^{-4} lb/hr ^{238}U and 1.0×10^{-6} lb/hr ^{235}U . The activity in the dust stream is:

^{232}Th	0.0132 lb/hr	6.6×10^{-7} Ci/hr
^{238}U	1.31×10^{-4} lb/hr	1.98×10^{-8} Ci/hr
^{235}U	1.0×10^{-6} lb/hr	9.75×10^{-10} Ci/hr
^{232}Th Daughters (9)	Trace	5.95×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	2.58×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	9.75×10^{-9} Ci/hr

Drying and Ignition Dust

From the drying and ignition processes, 896.2 lb/hr of airborne wastes are emitted, of which 0.12 lb are ^{232}Th . The remainder is mostly H_2O .

The activity in the stream is:

^{232}Th	0.105 lb/hr	5.25×10^{-6} Ci/hr
^{228}Th	Trace	5.25×10^{-6} Ci/hr

The equipment that handles this dust load consists of a 21,000-cfm wet-impingement scrubber.

Packaging Dust

From the packaging process, 0.021 lb/hr of airborne wastes are released, of which 0.0185 lb/hr are ^{232}Th . The activity of the stream is:

FIGURE D.2. Lemhi Pass Mill/Refinery Flowsheet

FIGURE D.2. Legend: Flow Streams for Lemhi Pass Mill/Refinery

1. 45.5 tons/hr ore w/285.38 lb/hr ^{232}Th
2. 4.55 lb/hr w/0.0132 lb/hr ^{232}Th
3. 18.2 tons/hr H_2O or 72.8 gpm
4. 63.7 tons/hr w/285.37 lb/hr ^{232}Th
5. 16,835 lb/hr H_2SO_4
6. 72.12 lb/hr w/285.37 lb/hr ^{232}Th
7. 4.55 tons/hr of H_2O (flocculant)
8. 168.35 tons/hr of wash H_2O
9. 45% solids - 63.39 tons/hr solids w/20.86 lb/hr ^{232}Th
55% solution - 77.475 tons/hr solution w/2.45 lb/hr ^{232}Th
10. 104.155 tons/hr w/262.06 lb/hr ^{232}Th
11. 104.155 tons/hr w/1.64 lb/hr ^{232}Th
12. 19.5 tons/hr w/260.42 lb/hr ^{232}Th
13. 19.5 tons/hr of stripped organic
14. 12.7 tons/hr of strip solution
15. 12.7 tons/hr w/260.42 lb/hr ^{232}Th
16. 590.5 lb/hr Na_2CO_3
17. 9.35 lb/hr $\text{Na}_2\text{S}_2\text{O}_4$
18. 13 tons/hr w/260.42 lb/hr ^{232}Th
19. 3.16 tons/hr of wash solution (3% Na_2SO_4)
20. 12.49 tons/hr w/0.55 lb/hr ^{232}Th
21. 3.67 tons/hr w/259.87 lb/hr ^{232}Th
22. 95.5 lb/hr of NaOH
23. 3.72 tons/hr w/259.87 lb/hr ^{232}Th
24. 3.177 tons/hr of wash H_2O
25. 6.25 tons/hr w/0.0273 lb/hr ^{232}Th
26. 0.597 tons/hr w/259.84 lb/hr ^{232}Th
27. 896.2 lb/hr w/0.105 lb/hr ^{232}Th
28. 297.8 lb/hr w/259.735 lb/hr ^{232}Th
29. 0.021 lb/hr w/0.0185 lb/hr ^{232}Th
30. 297.8 lb/hr w/259.72 lb/hr ^{232}Th

^{232}Th	0.0185 lb/hr	9.25×10^{-7} Ci/hr
^{228}Th	Trace	9.25×10^{-7} Ci/hr

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Counter Current Decantation Stream - 45% solids = 63.39 tons/hr containing 20.86 lb/hr ^{232}Th and 77.475 tons/hr of solution containing 2.45 lb/hr ^{232}Th with a total flow of 309.9 gpm.

Amine Extraction Stream - 104.155 tons/hr containing 1.64 lb/hr ^{232}Th with a total flow of 416.6 gpm.

Dewatering Stream - 12.49 tons/hr containing 0.55 lb/hr ^{232}Th with a total flow of 49.95 gpm.

Filtration Stream - 6.25 tons/hr containing 0.0273 lb/hr ^{232}Th with a total flow of 25.0 gpm.

The total amount of liquid waste sent to the tailings pond = 263.76 tons/hr containing 25.527 lb/hr ^{232}Th . The total flow to the pond is 801.45 gpm. All of the uranium in the entering ore goes to the tailings pond except the amount emitted as dust from the unloading, crushing, and grinding stage. The amounts of uranium are:

Total uranium in entering ore = $(0.01)(285.38 \text{ lb/hr}) = 2.854 \text{ lb/hr}$

U in tailings pond = $2.854 - (1.32 \times 10^{-4}) = 2.8539 \text{ lb/hr}$

$^{238}\text{U} = (0.993)(2.8539) = 2.834 \text{ lb/hr}$

$^{235}\text{U} = (0.007)(2.8539) = 0.020 \text{ lb/hr}$

The activity in the tailings pond is:

^{232}Th	25.527 lb/hr	1.276×10^{-3} Ci/hr
^{238}U	2.834 lb/hr	4.287×10^{-4} Ci/hr
^{235}U	0.02 lb/hr	1.945×10^{-5} Ci/hr
^{232}Th Daughters	Trace	1.1541×10^{-1} Ci/hr
^{238}U Daughters (13)	Trace	5.573×10^{-3} Ci/hr
^{235}U Daughters (10)	Trace	1.945×10^{-4} Ci/hr

D.3 GENERATED WASTES FROM HALL MOUNTAIN THORITE MILL/REFINERY

Dust from Unloading, Crushing, and Grinding the Ore

From these processes, 1.818 lb/hr of ore are emitted in dust; of this, 0.0176 lb/hr is ^{232}Th , as shown in Figure D.3. The uranium content of the dust is $(0.01)(\text{U/Th})$; so $(0.01)(1.76 \times 10^{-2}) = 1.76 \times 10^{-4}$ lb/hr U. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

so 1.75×10^{-4} lb/hr ^{238}U and 1.0×10^{-6} lb/hr ^{235}U are emitted. The activity in the dust stream is:

^{232}Th	1.76×10^{-2} lb hr	8.80×10^{-7} Ci/hr
^{238}U	1.75×10^{-4} lb/hr	2.65×10^{-8} Ci/hr
^{235}U	1.0×10^{-6} lb/hr	9.73×10^{-10} Ci/hr
^{232}Th Daughters (9)	Trace	7.92×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	3.44×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	9.73×10^{-6} Ci/hr

Drying and Ignition Dust

These processes emit 292.3 lb/hr of airborne wastes, of which 0.1275 lb/hr is ^{232}Th . The remainder is mostly H_2O . The activity in the stream is:

^{232}Th	0.1275 lb/hr	6.375×10^{-6} Ci/hr
^{228}Th	Trace	6.375×10^{-6} Ci/hr

Packaging Dust

This process emits 0.0227 lb/hr of airborne wastes of which 0.0225 lb/hr is ^{232}Th . The activity of the dust stream is:

^{232}Th	0.0225 lb/hr	1.125×10^{-6} Ci/hr
^{228}Th	Trace	1.125×10^{-6} Ci/hr

FIGURE D.3. Hall Mountain Mill/Refinery Flowsheet

FIGURE D.3. Legend: Flow Streams for Hall Mountain Mill/Refinery

1. 18.18 tons/hr ore w/352 lb/hr ^{232}Th
2. 1.818 lb/hr w/ 1.76×10^{-2} lb/hr ^{232}Th
3. 7.272 tons/hr H_2O or 29.08 gpm
4. 25.451 tons/hr w/351.98 lb/hr ^{232}Th
5. 6726.6 lb/hr H_2SO_4
6. 28.814 tons/hr w/351.98 lb/hr ^{232}Th
7. 1.818 tons of H_2O (flocculant)
8. 67.3 tons of wash water
9. 45% solution - 17.604 tons/hr solids w/25.73 lb/hr ^{232}Th
55% solution - 20.38 tons/hr solution w/3.045 lb/hr ^{232}Th
10. 59.948 tons/hr w/323.205 lb/hr ^{232}Th
11. 59.948 tons/hr w/2.02 lb/hr ^{232}Th
12. 5.42 tons/hr w/321.185 lb/hr ^{232}Th
13. 5.42 tons/hr of stripped organic
14. 7.39 tons/hr of strip solution
15. 7.39 tons/hr w/321.185 lb/hr ^{232}Th
16. 363.6 lb/hr Na_2CO_3
17. 5.454 lb/hr $\text{Na}_2\text{S}_2\text{O}_2$
18. 7.57 tons/hr w/321.185 lb/hr ^{232}Th
19. 1.818 tons/hr of wash solution (3% Na_2SO_4)
20. 7.269 tons/hr w/0.680 lb/hr ^{232}Th
21. 2.119 tons/hr w/320.505 lb/hr ^{232}Th
22. 54.54 lb/hr of NaOH
23. 2.146 tons/hr w/320.505 lb/hr ^{232}Th
24. 1.818 tons/hr of wash H_2O
25. 3.634 tons/hr w/0.035 lb/hr ^{232}Th
26. 0.330 tons/hr w/320.47 lb/hr ^{232}Th
27. 292.3 lb/hr w/0.1275 lb/hr ^{232}Th
28. 367.7 lb/hr w/320.3425 lb/hr ^{232}Th
29. 0.0227 lb/hr w/0.0225 lb/hr ^{232}Th
30. 367.7 lb/hr w/320.32 lb/hr ^{232}Th

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Counter Current Decantation Stream - 45% solids = 17.60 tons/hr
containing 25.73 lb/hr ^{232}Th ; 55% solution = 20.38 ton/hr
containing 3.045 lb/hr ^{232}Th ; the total flow is 81.52 gpm.

Amine Extraction Stream - 59.948 tons/hr containing 2.02 lb/hr
 ^{232}Th with a total flow of 239.79 gpm.

Dewatering Stream - 7.269 tons/hr containing 0.680 lb/hr ^{232}Th
with a total flow of 29.1 gpm.

Filtration Stream - 3.634/tons/hr containing 0.035 lb/hr ^{232}Th
with a total flow of 14.54 gpm.

The total amount sent to the tailings pond is 108.83 tons/hr containing
31.51 lb/hr ^{232}Th . The total flow to the pond is 364.95 gpm. All of the
uranium in the entering ore goes to the tailings pond except for the amount
emitted as dust from the unloading, crushing, and grinding stage. The amounts
of uranium are:

Total uranium in entering ore = $(0.01)(352 \text{ lb/hr}) = 3.52 \text{ lb/hr}$

U in tailings pond = $3.52 - (1.76 \times 10^{-4}) = 3.5198 \text{ lb/hr}$

$^{238}\text{U} = (0.993)(3.5198) = 3.4952 \text{ lb/hr}$

$^{235}\text{U} = 2.46 \times 10^{-2} \text{ lb/hr}$

The activity in the tailings pond is:

^{232}Th	31.51 lb/hr	$1.575 \times 10^{-3} \text{ Ci/hr}$
^{238}U	3.4952 lb/hr	$5.29 \times 10^{-4} \text{ Ci/hr}$
^{235}U	$2.46 \times 10^{-2} \text{ lb/hr}$	$2.39 \times 10^{-5} \text{ Ci/hr}$
^{232}Th Daughters	Trace	$1.42 \times 10^{-1} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$6.87 \times 10^{-3} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$2.39 \times 10^{-4} \text{ Ci/hr}$

D.4 GENERATED WASTES FROM WET MOUNTAIN THORITE MILL/REFINERY

Dust from Unloading, Crushing, and Grinding the Ore

This stream contains 1.6 lb/hr of ore in its dust; of this, 0.0123 lb/hr is ^{232}Th . The uranium content of the dust is (100/1)(Th/U); so (0.0123)(0.01) = 1.232×10^{-4} lb/hr U. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

There are 1.22×10^{-4} lb ^{238}U and 8.6×10^{-7} lb ^{235}U . The activity in the dust stream is:

^{232}Th	0.0123 lb/hr	6.15×10^{-7} Ci/hr
^{238}U	1.22×10^{-4} lb/hr	1.845×10^{-8} Ci/hr
^{235}U	8.6×10^{-7} lb/hr	8.37×10^{-10} Ci/hr
^{232}Th Daughters (9)	Trace	5.535×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	2.3985×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	8.37×10^{-9} Ci/hr

Drying and Ignition Dust

The dust stream from these processes contains 119.2 lb/hr of airborne wastes, of which 0.0972 lb/hr is ^{232}Th , as shown in Figure D.4. The remainder is mostly H_2O . The activity in the stream is:

^{232}Th	0.0972 lb/hr	4.86×10^{-6} Ci/hr
^{228}Th Daughters	Trace	4.86×10^{-6} Ci/hr

Packaging Dust

The packaging process emits 0.0197 lb/hr of airborne wastes of which 0.0172 lb/hr are ^{232}Th . The activity in the stream is:

^{232}Th	0.0172 lb/hr	8.60×10^{-7} Ci/hr
^{228}Th	Trace	8.60×10^{-7} Ci/hr

FIGURE D.4. Wet Mountain Mill/Refinery Flowsheet

FIGURE D.4. Legend: Flow Streams for Wet Mountain Mill/Refinery

1. 15.91 tons/hr ore w/268.84 lb/hr ^{232}Th
2. 1.6 lb/hr w/0.0123 lb/hr ^{232}Th
3. 6.36 tons/hr H_2O or 25.46 gpm
4. 22.27 tons/hr w/268.83 lb/hr ^{232}Th
5. 5887 lb/hr H_2SO_4
6. 25.21 tons/hr w/268.83 lb/hr ^{232}Th
7. 1.6 tons of H_2O (flocculant)
8. 58.87 tons of wash H_2O
9. 45% solids - 22.16 tons/hr solids w/19.65 lb/hr ^{232}Th
55% solution - 27.09 tons/hr solution w/2.325 lb/hr ^{232}Th
10. 36.43 tons/hr w/243.85 lb/hr ^{232}Th
11. 36.43 tons/hr w/1.55 lb/hr ^{232}Th
12. 6.82 tons/hr w/245.3 lb/hr ^{232}Th
13. 6.82 tons/hr of stripped organic
14. 4.44 tons/hr of strip solution
15. 4.44 tons/hr w/245.3 lb/hr ^{232}Th
16. 206.48 lb/hr Na_2CO_3
17. 3.27 lb/hr $\text{Na}_2\text{S}_2\text{O}_4$
18. 4.55 tons/hr w/245.3 lb/hr ^{232}Th
19. 1.10 tons/hr of wash solution
20. 4.37 tons/hr w/0.52 lb/hr ^{232}Th
21. 1.28 tons/hr w/244.78 lb/hr ^{232}Th
22. 33.4 lb/hr of NaOH
23. 1.30 tons/hr w/244.78 lb/hr ^{232}Th
24. 1.09 tons/hr of wash H_2O
25. 2.19 tons/hr w/0.0264 lb/hr ^{232}Th
26. 400 tons/hr w/244.75 lb/hr ^{232}Th
27. 119.2 lb/hr w/0.0972 lb/hr ^{232}Th
28. 280.8 lb/hr w/244.66 lb/hr ^{232}Th
29. 0.0197 lb/hr w/0.0172 lb/hr ^{232}Th
30. 280.8 lb/hr w/244.64 lb/hr ^{232}Th

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Counter Current Decantation Stream - 45% solids = 22.16 tons/hr
containing 19.65 lb/hr ^{232}Th , and 27.09 ton/hr of solution
containing 2.325 lb/hr ^{232}Th ; total flow is 108.4 gpm.

Amine Extraction Stream - 36.43 tons/hr containing 1.55 lb/hr
 ^{232}Th with a total flow of 145.7 gpm.

Dewatering Stream - 4.37 tons/hr containing 0.52 lb/hr ^{232}Th with
a total flow of 17.5 gpm.

Filtration Stream - 2.19/tons/hr containing 0.0264 lb/hr ^{232}Th
with a total flow of 8.76 gpm.

The total amount sent to the tailings pond is 92.24 tons/hr containing
24.07 lb/hr ^{232}Th . The total flow to the pond is 280.4 gpm. All of the
uranium in the entering ore goes to the tailings pond except the amount
emitted as dust from the unloading, crushing, and grinding stage. The amounts
of uranium are:

$$\text{Total uranium in entering ore} = (0.01)(236.84 \text{ lb/hr}) = 2.6884 \text{ lb/hr}$$

$$\text{U in tailings pond} = 2.6884 - (1.232 \times 10^{-4}) = 2.6883 \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(2.6883) = 2.669 \text{ lb/hr}$$

$$^{235}\text{U} = (0.007)(2.6883) = 0.0193 \text{ lb/hr}$$

The activity in the tailings pond is:

^{232}Th	24.07 lb/hr	$1.20 \times 10^{-3} \text{ Ci/hr}$
^{238}U	2.669 lb/hr	$4.04 \times 10^{-4} \text{ Ci/hr}$
^{235}U	0.0193 lb/hr	$1.88 \times 10^{-5} \text{ Ci/hr}$
^{232}Th Daughters	Trace	$1.087 \times 10^{-1} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$5.25 \times 10^{-3} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$1.88 \times 10^{-4} \text{ Ci/hr}$

D.5 GENERATED WASTES FROM PALMER, MICHIGAN, ORE MILL

Dust from Unloading, Crushing, and Grinding the Ore

The unloading, crushing, and grinding areas of the mill emit 327.2 lb/hr of ore dust; of this, 0.172 lb/hr is ^{232}Th , and shown in Figure D.5. The uranium content of the dust is (23/1)(Th/U); so $(0.0435)(0.172) = 7.478 \times 10^{-3}$ lb/hr U. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

Thus, there are 7.426×10^{-3} lb ^{238}U and 5.20×10^{-5} lb/hr ^{235}U . The activity in the dust stream is:

^{232}Th	0.172 lb/hr	8.60×10^{-6} Ci/hr
^{238}U	7.426×10^{-3} lb/hr	1.12×10^{-6} Ci/hr
^{235}U	5.20×10^{-5} lb/hr	5.06×10^{-8} Ci/hr
^{232}Th Daughters (9)	Trace	7.74×10^{-5} Ci/hr
^{238}U Daughters (13)	Trace	1.46×10^{-5} Ci/hr
^{235}U Daughters (10)	Trace	5.06×10^{-7} Ci/hr

Dust from Drying, Magnetic Separating, and Loading

These processes emit 2.455 tons/hr of airborne effluents, of which 0.101 lb/hr are ^{232}Th ; the remainder is mostly H_2O . The uranium content of the dust is $(0.0435)(\text{U}/\text{Th})$; so $(0.101)(0.0435) = 4.4 \times 10^{-3}$ lb/hr U, which can be broken down into:

$$^{238}\text{U} = (0.993)(4.4 \times 10^{-3}) = 4.369 \times 10^{-3} \text{ lb/hr}$$

$$^{235}\text{U} = 3.1 \times 10^{-5} \text{ lb/hr}$$

The activity in the dust stream is:

^{232}Th	0.101 lb/hr	5.05×10^{-6} Ci/hr
^{238}U	4.369×10^{-3} lb/hr	6.61×10^{-7} Ci/hr
^{235}U	3.1×10^{-5} lb/hr	3.02×10^{-8} Ci/hr

FIGURE D.5. Palmer, Michigan, Mill Flowsheet

FIGURE D.5. Legend: Flow Streams for Palmer, Michigan, Ore Mill

1. 1895.45 tons/hr ore w/0.98912 ton/hr ^{232}Th
2. 189.545 lb/hr w/0.0989 lb/hr ^{232}Th
3. 1377.27 tons/hr ore w/0.7187 ton/hr ^{232}Th
4. 137.7 lb/hr w/0.073 lb/hr ^{232}Th
5. 1377.20 tons/hr 0.7187 ton/hr ^{232}Th
6. 8656.96 tons/hr H_2O and 1347.04 tons/hr ore w/0.2762 ton/hr ^{232}Th
7. 311.13 tons/hr H_2O and 1225.78 tons/hr ore w/0.2488 ton/hr ^{232}Th
8. 779.12 tons/hr H_2O and 121.26 tons/hr ore w/0.0274 ton/hr ^{232}Th
9. 1092.65 tons/hr H_2O
10. 8659.36 tons/hr H_2O
11. 2.40 tons/hr H_2O and 30.16 tons/hr ore w/0.4425 ton/hr ^{232}Th
12. 2.40 tons/hr H_2O and 109.98 lb/hr ore w/0.057 lb/hr ^{232}Th
13. 20.60 tons/hr w/8.40 lb/hr ^{232}Th
14. 9.505 tons/hr w/876.5 lb/hr
15. 0.95 lb/hr w/0.044 lb/hr ^{232}Th
16. 9.505 tons/hr w/876.5 lb/hr

^{232}Th Daughters (9)	Trace	4.544×10^{-5} Ci/hr
^{238}U Daughters (13)	Trace	8.59×10^{-6} Ci/hr
^{235}U Daughters (10)	Trace	3.02×10^{-7} Ci/hr

Liquid Waste to Evaporation Pond

The total amount of liquid waste sent to an evaporation pond is 799.12 tons/hr H_2O containing 121.26 tons/hr ore and 0.0274 tons/hr ^{232}Th . It also contains uranium in these amounts:

$$\text{Uranium content of waste} = (0.0274)(0.0435) = 2.38 \text{ lb/hr U}$$

$$^{238}\text{U} = (0.993)(2.38) = 2.37 \text{ lb/hr}$$

$$^{235}\text{U} = 0.01 \text{ lb/hr}$$

The activity in the evaporation pond is:

^{232}Th	54.8 lb/hr	2.74×10^{-3} Ci/hr
^{238}U	2.37 lb/hr	3.59×10^{-4} Ci/hr
^{235}U	0.01 lb/hr	9.73×10^{-6} Ci/hr
^{232}Th Daughters (9)	Trace	2.47×10^{-2} Ci/hr
^{238}U Daughters (13)	Trace	4.66×10^{-3} Ci/hr
^{235}U Daughters (10)	Trace	9.73×10^{-4} Ci/hr

Solid Waste Returned To Mine

The following two streams are returned to the mine for disposal:

Dewatered Ore Waste - 1536.91 tons/hr (80% solids) containing 497.6 lb/hr ^{232}Th .

Ore from Magnetic Separation - 20.60 tons/hr containing 8.4 lb/hr ^{232}Th .

The total amount returned to mine is 1557.51 tons/hr containing 506.0 lb/hr ^{232}Th and contains these amounts of uranium:

Uranium content = $(0.0435)(506.0) = 22.0$ lb/hr

$^{238}\text{U} = (0.993)(22.0) = 21.85$ lb/hr

$^{235}\text{U} = 0.15$ lb/hr

The activity in the solid waste is:

^{232}Th	506.0 lb/hr	2.53×10^{-2} Ci/hr
^{238}U	22.0 lb/hr	3.328×10^{-3} Ci/hr
^{235}U	0.15 lb/hr	1.46×10^{-4} Ci/hr
^{232}Th Daughters (9)	Trace	2.277×10^{-1} Ci/hr
^{238}U Daughters (13)	Trace	4.326×10^{-3} Ci/hr
^{235}U Daughters (10)	Trace	1.46×10^{-4} Ci/hr

D.6 GENERATED WASTES FROM PALMER, MICHIGAN, MILL/REFINERY

Dust from Unloading, and Grinding

These processes emit 0.9505 lb/hr of airborne wastes, of which 0.044 lb/hr is ^{232}Th . The uranium content of the dust is $(0.0435)(\text{U/Th})$; so $(0.0435)(0.044) = 1.913 \times 10^{-3}$ lb/hr U. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

There are 1.90×10^{-3} lb/hr ^{238}U and 1.30×10^{-5} lb/hr ^{235}U . The activity in the dust stream is:

^{232}Th	0.044 lb/hr	2.20×10^{-6} Ci/hr
^{238}U	1.9×10^{-3} lb/hr	2.87×10^{-7} Ci/hr
^{235}U	1.3×10^{-5} lb/hr	1.265×10^{-8} Ci/hr
^{232}Th Daughters (9)	Trace	1.98×10^{-5} Ci/hr
^{238}U Daughters (13)	Trace	3.73×10^{-6} Ci/hr
^{235}U Daughters (10)	Trace	1.265×10^{-7} Ci/hr

Dust from Ignition and Drying

The ignition and drying processes emit 1218 lb/hr of airborne wastes, of which 0.803 lb/hr are ^{232}Th . The remainder is mostly H_2O , as shown in Figure D.6. The activity in the stream is:

^{232}Th	0.803 lb/hr	4.01×10^{-5} Ci/hr
^{228}Th	Trace	4.01×10^{-5} Ci/hr

Packaging Dust

The packaging process emits 0.1596 lb/hr of airborne wastes of which 0.139 lb/hr are ^{232}Th . The activity of the stream is:

^{232}Th	0.139 lb/hr	6.95×10^{-6} Ci/hr
^{228}Th	Trace	6.95×10^{-6} Ci/hr

FIGURE D.6. Palmer, Michigan, Refinery Flowsheet

FIGURE D.6. Legend: Flow Streams for Palmer, Michigan, Refinery

1. 9.505 tons/hr concentrate w/876.48 lb/hr ^{232}Th	21. 0.9505 ton/hr Na_2CO_3
2. 0.9505 lb/hr w/0.044 lb/hr ^{232}Th	22. 38.9705 tons/hr w/844.63 lb/hr ^{232}Th
3. 9.505 tons/hr w/876.436 lb/hr ^{232}Th	23. 38.02 tons/hr w/0.779 lb/hr ^{232}Th
4. 16.01 tons/hr H_2SO_4	24. 0.9505 ton/hr w/843.85 lb/hr
5. 25.51 tons/hr w/876.436 lb/hr ^{232}Th	25. 285.15 lb/hr NaOH
6. 47.525 tons/hr H_2O	26. 1.90 tons/hr H_2O
7. 73.035 tons/hr w/876.436 lb/hr ^{232}Th	27. 2.993 tons/hr w/843.85 lb/hr ^{232}Th
8. 1.90 lb/hr flocculant	28. 1.90 tons/hr wash solution
9. 24.71 tons/hr H_2O	29. 3.80 tons/hr w/0.080 lb/hr ^{232}Th
10. 48.47 tons/hr wash solution w/0.7788 lb/hr ^{232}Th	30. 1.093 tons/hr w/843.77 lb/hr ^{232}Th
11. 26.46 tons/hr w/30.254 lb/hr ^{232}Th	31. 0.609 tons/hr w/0.803 lb/hr ^{232}Th
12. 121/505 tons/hr w/846.96 lb/hr ^{232}Th	32. 968.0 lb/hr w/842.967 lb/hr ^{232}Th
13. 71.29 tons/hr organic (10% JM-T, 5% PDA, 85% kerosene)	33. 0.1596 lb/hr w/0.139 lb/hr ^{232}Th
14. 121.505 tons/hr w/1.55 lb/hr ^{232}Th	34. 967.84 lb/hr w/842.831 lb/hr ^{232}Th
15. 71.29 tons/hr w/845.41 lb/hr ^{232}Th	35. 5.7 tons/hr NaSO_4
16. 23.76 tons/hr of scrub solution (0.2M H_2SO_4)	36. 127.205 tons/hr w/1.55 lb/hr ^{232}Th
17. 23.76 tons/hr w/0.779 lb/hr ^{232}Th	37. 94.9 tons/hr w/1.05 lb/hr ^{232}Th
18. 71.29 tons/hr w/844.63 lb/hr ^{232}Th	38. 32.3 tons/hr w/0.50 lb/hr ^{232}Th
19. 38.02 tons/hr strip solution (1.5M NaCl, 0.5M HCl)	39. 9.1 tons/hr NaOH (30%)
20. 38.02 tons/hr w/844.63 lb/hr ^{232}Th	40. 41.4 tons/hr w/0.50 lb/hr ^{232}Th
	41. 10.2 tons/hr H_2O
	42. 41.0 tons/hr w/0.11 lb/hr ^{232}Th
	43. 10.6 tons/hr w/0.39 lb/hr ^{232}Th
	44. 3.2 tons/hr w/0.0062 lb/hr ^{232}Th
	45. 7.4 tons/hr w/0.384 lb/hr ^{232}Th (46% REO)

The activity in the stream is:

^{232}Th	0.139 lb/hr	6.95×10^{-6} Ci/hr
^{228}Th	Trace	6.95×10^{-6} Ci/hr

Drying and Packaging Dust from By-Product Recovery System

These processes emit 3.2 tons/hr of airborne wastes, of which 0.0062 lb/hr are ^{232}Th . The remainder is mostly H_2O . This dust stream also contains uranium in these amounts:

$$\text{Uranium content of dust} = (0.0435)(0.0062) = 2.696 \times 10^{-4} \text{ lb/hr.}$$

$$^{238}\text{U} = (0.993)(2.696 \times 10^{-4}) = 2.68 \times 10^{-4} \text{ lb/hr}$$

$$^{235}\text{U} = 1.6 \times 10^{-6} \text{ lb/hr}$$

The activity of the stream is:

^{232}Th	0.0062 lb/hr	3.10×10^{-7} Ci/hr
^{238}U	2.68×10^{-4} lb/hr	4.05×10^{-8} Ci/hr
^{235}U	1.6×10^{-6} lb/hr	1.56×10^{-9} Ci/hr
^{232}Th Daughters (9)	Trace	2.79×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	5.27×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	1.56×10^{-8} Ci/hr

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Filtration I Stream - 26.46 tons/hr containing 30.254 lb/hr ^{232}Th
with a total flow of 105.8 gpm.

Filtration II Stream - 38.02 tons/hr containing 0.779 lb/hr ^{232}Th
with a total flow of 152 gpm.

Filtration III Stream - 3.80 tons/hr containing 0.080 lb/hr ^{232}Th
with a total flow of 15.2 gpm.

Filtration IV Stream - 94.9 tons/hr containing 1.05 lb/hr ^{232}Th
with a total flow of 379.6 gpm.

Filtration V Stream - 41.0 tons/hr containing 0.11 lb/hr ^{232}Th
with a total flow of 16.4 gpm.

The total amount of liquid waste sent to the tailings pond is 204.18 tons/hr containing 32.273 lb/hr ^{232}Th . The total flow to the pond is 816.72 gpm. All of the uranium in the entering ore goes to the tailings pond except for the amount emitted as dust and as a by-product. The amounts of uranium are:

$$\text{Total uranium in entering ore} = (0.0435)(876.48) = 38.10783 \text{ lb/hr.}$$

$$\text{Uranium in by-product} = (0.0435)(0.384) = 1.6696 \times 10^{-2} \text{ lb/hr}$$

$$\begin{aligned} \text{Uranium in tailings pond} &= 38.108 - (1.6696 \times 10^{-2}) + (1.913 \times 10^{-3}) + (2.696 \times 10^{-4}) \\ &= 38.089 \text{ lb/hr} \end{aligned}$$

$$^{238}\text{U} = (0.993)(38.089) = 37.82 \text{ lb/hr}$$

$$^{235}\text{U} = 0.269 \text{ lb/hr}$$

All of the ^{232}Th daughters end up in the tailings pond except those emitted with the dust or in the by-product. The activity in the tailings pond is:

^{232}Th	32.273 lb/hr	$1.6134 \times 10^{-3} \text{ Ci/hr}$
^{238}U	37.82 lb/hr	$5.721 \times 10^{-4} \text{ Ci/hr}$
^{235}U	0.269 lb/hr	$2.618 \times 10^{-6} \text{ Ci/hr}$
^{232}Th Daughters	Trace	$3.5198 \times 10^{-1} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$7.437 \times 10^{-2} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$2.618 \times 10^{-3} \text{ Ci/hr}$

D.7 GENERATED WASTES FROM BALD MOUNTAIN ORE MILL

Dust from Unloading, Crushing, and Grinding

In the unloading, crushing, and grinding areas of the mill, 78.515 lb/hr of ore dust are released; of this, 6.551×10^{-3} lb/hr is ^{232}Th , as shown in Figure D.7. The uranium content of the dust is $(0.0435)(6.55 \times 10^{-3}) = 2.848 \times 10^{-4}$ lb/hr. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

There are 2.828×10^{-4} lb/hr ^{238}U and 2.0×10^{-6} lb/hr ^{235}U .

The activity in the dust stream is:

^{232}Th	6.55×10^{-3} lb/hr	3.27×10^{-7} Ci/hr
^{238}U	2.828×10^{-4} lb/hr	4.28×10^{-8} Ci/hr
^{235}U	2.0×10^{-6} lb/hr	1.95×10^{-9} Ci/hr
^{232}Th Daughters (9)	Trace	2.95×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	5.56×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	1.95×10^{-8} Ci/hr

Dust from Drying, Magnetic Separating, and Loading

These processes release 173.92 lb/hr of airborne wastes, of which 3.414×10^{-3} lb/hr are ^{232}Th . The remainder is mostly H_2O . The wastes also contain uranium in these amounts:

$$\text{Uranium content of dust} = (0.0435)(3.414 \times 10^{-3}) = 1.48 \times 10^{-4} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.48 \times 10^{-4}) = 1.474 \times 10^{-4} \text{ lb/hr}$$

$$^{235}\text{U} = 6.0 \times 10^{-7} \text{ lb/hr}$$

The activity in the dust stream is:

^{232}Th	3.414×10^{-3} lb/hr	1.71×10^{-7} Ci/hr
^{238}U	1.474×10^{-4} lb/hr	2.23×10^{-8} Ci/hr
^{235}U	6.0×10^{-7} lb/hr	5.84×10^{-10} Ci/hr

FIGURE D.7. Bald Mountain Mill Flowsheet

FIGURE D.7. Legend: Flow Streams for Bald Mountain Mill

1. 454.55 tons/hr ore w/76.08 ton/hr ^{232}Th
2. 45.455 lb/hr w/ 3.784×10^{-3} lb/hr ^{232}Th
3. 330.58 tons/hr w/55.33 lb/hr ^{232}Th
4. 33.06 lb/hr w/ 2.767×10^{-3} lb/hr ^{232}Th
5. 330.56 tons/hr w/55.33 lb/hr ^{232}Th
6. 2078.435 tons/hr H_2O and 329.492 tons/hr ore w/21.25 lb/hr ^{232}Th
7. 74.70 tons/hr H_2O and 299.83 tons/hr ore w/19.14 lb/hr ^{232}Th
8. 187.06 tons/hr H_2O and 29.662 tons/hr ore w/2.111 lb/hr ^{232}Th
9. 261.845 tons/hr H_2O
10. 2078.52 tons/hr H_2O
11. 170 lb /hr H_2O and 1.068 tons/hr ore w/34.08 lb/hr ^{232}Th
12. 170 lb/hr H_2O and 3.89 lb/hr ore w/ 2.024×10^{-3} lb/hr ^{232}Th
13. 1459 lb/hr ore w/0.326 lb/hr ^{232}Th
14. 673.11 lb/hr ore w/33.75 lb/hr ^{232}Th
15. 0.03 lb/hr ore w/ 1.39×10^{-3} lb/hr ^{232}Th
16. 673.08 lb/hr w/33.75 lb/hr

^{232}Th Daughters(9)	Trace	1.54×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	2.90×10^{-7} Ci/hr
^{235}U Daughters (10)	Trace	5.84×10^{-9} Ci/hr

Liquid Waste to Evaporation Pond

The liquid wastes sent to an evaporation pond total 187.06 tons/hr H_2O . They contain 29.662 tons/hr ore, 2.112 lb/hr ^{232}Th , and these amounts of uranium:

$$\text{Uranium content of waste} = (0.0435)(2.112) = 9.183 \times 10^{-2} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(9.183 \times 10^{-2}) = 9.119 \times 10^{-2} \text{ lb/hr}$$

$$^{235}\text{U} = 6.4 \times 10^{-4} \text{ lb/hr}$$

The activity in the evaporation pond is:

^{232}Th	2.112 lb/hr	1.06×10^{-4} Ci/hr
^{238}U	9.119×10^{-2} lb/hr	1.38×10^{-5} Ci/hr
^{235}U	6.4×10^{-4} lb/hr	6.23×10^{-7} Ci/hr
^{232}Th Daughters (9)	Trace	9.54×10^{-4} Ci/hr
^{238}U Daughters (13)	Trace	1.79×10^{-4} Ci/hr
^{235}U Daughters (10)	Trace	6.23×10^{-6} Ci/hr

Solid Waste Returned To Mine

The following two streams are returned to the mine for disposal:

Dewatered Ore Waste - 374.53 tons/hr (80% solids) containing 19.14 lb/hr ^{232}Th .

Ore from Magnetic Separation - 1459 lb/hr containing 0.326 lb/hr ^{232}Th .

The total amount returned to the mine is 375.26 tons/hr containing 19.47 lb/hr ^{232}Th and these amounts of uranium:

$$\text{Uranium content} = (0.0435)(19.47) = 0.8465 \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(0.8465) = 0.8406 \text{ lb/hr}$$

$$^{235}\text{U} = 5.9 \times 10^{-3} \text{ lb/hr}$$

The activity in the solid waste is:

^{232}Th	19.47 lb/hr	9.73×10^{-4} Ci/hr
^{238}U	0.8406 lb/hr	1.27×10^{-4} Ci/hr
^{235}U	5.9×10^{-3} lb/hr	5.74×10^{-6} Ci/hr
^{232}Th Daughters (9)	Trace	8.76×10^{-3} Ci/hr
^{238}U Daughters (13)	Trace	1.65×10^{-3} Ci/hr
^{235}U Daughters (10)	Trace	5.74×10^{-5} Ci/hr

D.8 GENERATED WASTES FROM BALD MOUNTAIN REFINERY

Unloading and Grinding Dust

As shown in Figure D.8, 0.03 lb/hr of airborne wastes are emitted, of which 1.50×10^{-3} lb/hr is ^{232}Th . The uranium content of the dust is (0.0435)(U/Th); so that amounts of uranium are:

$$\text{U} = (0.0435)(1.50 \times 10^{-3}) = 6.52 \times 10^{-5} \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(6.52 \times 10^{-5}) = 6.47 \times 10^{-5} \text{ lb/hr}$$

$$^{235}\text{U} = 5.0 \times 10^{-7} \text{ lb/hr}$$

The activity in the dust stream is:

^{232}Th	$1.5 \times 10^{-3} \text{ lb/hr}$	$7.5 \times 10^{-8} \text{ Ci/hr}$
^{238}U	$6.47 \times 10^{-5} \text{ lb/hr}$	$9.79 \times 10^{-9} \text{ Ci/hr}$
^{235}U	$5.0 \times 10^{-7} \text{ lb/hr}$	$4.86 \times 10^{-10} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$6.75 \times 10^{-7} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$1.27 \times 10^{-7} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$4.86 \times 10^{-9} \text{ Ci/hr}$

Ignition and Drying Dust

These processes release 40.23 lb/hr of airborne wastes, of which 3.03×10^{-2} lb/hr is ^{232}Th ; the remainder is mostly H_2O . The activity in the dust stream is:

^{232}Th	$3.03 \times 10^{-2} \text{ lb/hr}$	$1.51 \times 10^{-6} \text{ Ci/hr}$
^{228}Th	Trace	$1.51 \times 10^{-6} \text{ Ci/hr}$

Packaging Dust

Packaging releases 6.2×10^{-3} lb/hr of airborne wastes, of which 5.4×10^{-3} lb/hr is ^{232}Th . The activity in the stream is:

^{232}Th	$5.4 \times 10^{-3} \text{ lb/hr}$	$2.70 \times 10^{-7} \text{ Ci/hr}$
^{228}Th	Trace	$2.70 \times 10^{-7} \text{ Ci/hr}$

Drying and Packaging Dust from By-Product Recovery System

This dust stream carries 164 lb/hr of airborne wastes, of which 2.3×10^{-4} lb/hr is ThO_2 ; the remainder is mostly H_2O . This stream also contains uranium in these amounts:

FIGURE D.8. Bald Mountain Refinery Flowsheet

FIGURE D.8. Legend: Flow Streams for Bald Mountain Refinery

1. 670 lb/hr ore w/33.60 lb/hr ^{232}Th	22. 1.37 tons/hr w/31.989 lb/hr ^{232}Th
2. 0.03 lb/hr w/ 1.50×10^{-3} lb/hr ^{232}Th	23. 1.34 tons/hr w/ 2.915×10^{-2} lb/hr ^{232}Th
3. 670 lb/hr w/33.60 lb/hr ^{232}Th	24. 66.803 lb/hr w/31.96 lb/hr ^{232}Th
4. 1128 lb/hr H_2SO_4	25. 10.05 lb/hr NaOH
5. 1798 lb/hr w/33.60 lb/hr ^{232}Th	26. 134.1 lb/hr H_2O
6. 1.675 tons/hr H_2O	27. 210.95 lb/hr w/31.96 lb/hr ^{232}Th
7. 2.574 tons/hr w/33.60 lb/hr ^{232}Th	28. 134.1 lb/hr wash solution
8. 6.7×10^{-2} lb/hr flocculant	29. 268.2 lb/hr w/ 3.02×10^{-3} lb/hr ^{232}Th
9. 1738 lb/hr H_2O	30. 76.85 lb/hr w/31.95 lb/hr ^{232}Th
10. 1.71 tons/hr wash solution
w/ 3.00×10^{-2} lb/hr ^{232}Th	31. 40.22 lb/hr w/ 3.03×10^{-2} lb/hr ^{232}Th
11. 1865 lb/hr w/1.13 lb/hr ^{232}Th	32. 36.62 lb/hr w/31.919 lb/hr ^{232}Th
12. 3.352 tons/hr w/32.50 lb/hr ^{232}Th	33. 6.2×10^{-3} lb/hr w/ 5.4×10^{-3} lb/hr
13. 2.51 tons/hr organic (10% JM-T,
5% PDA, 85% kerosene)	34. 36.62 lb/hr w/31.91 lb/hr ^{232}Th
14. 3.352 tons/hr w/0.481 lb/hr ^{232}Th	35. 402.7 lb/hr NaSO_4
15. 2.51 tons/hr w/32.019 lb/hr ^{232}Th	36. 3.553 tons/hr w/0.481 lb/hr ^{232}Th
16. 1682 lb/hr of scrub solution
(0.2 M H_2SO_4)	37. 1.597 tons/hr w/ 3.93×10^{-2} lb/hr ^{232}Th
17. 1682 lb/hr w/ 3.00×10^{-2} lb/hr ^{232}Th	38. 1.956 tons/hr w/0.4417 ^{232}Th
18. 2.51 tons/hr w/ 31.989 lb/hr ^{232}Th	39. 643 lb/hr NaOH (30%)
19. 1.34 tons/hr strip solution
(1.5 M NaCl, 0.5 M HCl)	40. 2.2775 tons/hr w/0.4417 lb/hr ^{232}Th
20. 1.34 tons/hr w/31.989 lb/hr ^{232}Th	41. 722 lb/hr H_2O
21. 66.803 lb/hr Na_2CO_3	42. 1.05 tons/hr w/ 1.48×10^{-2} lb/hr ^{232}Th
	43. 1.59 tons/hr w/0.427 lb/hr ^{232}Th
	44. 164 lb/hr w/ 2.3×10^{-4} lb/hr ^{232}Th
	45. 1.51 tons/hr w/0.4268 lb/hr ^{232}Th
(46% REO)

Uranium content of dust = $(0.0435)(2.3 \times 10^{-4}) = 1.0 \times 10^{-5}$ lb/hr

$$^{238}\text{U} = (0.993)(1.0 \times 10^{-5}) = 9.93 \times 10^{-6} \text{ lb/hr}$$

$$^{235}\text{U} = 7.0 \times 10^{-8} \text{ lb/hr}$$

The activity in the dust stream is:

^{232}Th	$2.3 \times 10^{-4} \text{ lb/hr}$	$1.15 \times 10^{-8} \text{ Ci/hr}$
^{238}U	$9.93 \times 10^{-6} \text{ lb/hr}$	$1.50 \times 10^{-9} \text{ Ci/hr}$
^{235}U	$7.0 \times 10^{-8} \text{ lb/hr}$	$6.81 \times 10^{-11} \text{ Ci/hr}$
^{232}Th Daughters (9)	Trace	$1.035 \times 10^{-7} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$1.95 \times 10^{-8} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$6.81 \times 10^{-10} \text{ Ci/hr}$

Liquid Waste to Tailings Pond

The following streams and respective loads are sent to a tailings pond:

Filtration I Stream - 1865 lb/hr containing 1.13 lb/hr ^{232}Th with a total flow of 3.73 gpm.

Filtration II Stream - 1.34 tons/hr containing 2.915×10^{-2} lb/hr ^{232}Th with a total flow of 5.36 gpm.

Filtration III Stream - 268.2 lb/hr containing 3.02×10^{-3} lb/hr ^{232}Th with a total flow of 0.536 gpm.

Filtration IV Stream - 1.597 tons/hr containing 3.93×10^{-2} lb/hr ^{232}Th with a total flow of 6.39 gpm.

Filtration V Stream - 1.05 tons/hr containing 1.48×10^{-2} lb/hr ^{232}Th with a total flow of 4.20 gpm.

The total amount of liquid waste sent to the tailings pond is 5.054 tons/hr containing 1.216 lb/hr. The total flow to the pond is 20.216 gpm. All of the uranium in the entering ore goes to the tailings pond except for the amount emitted as dust and as a by-product. The amounts of uranium are:

$$\text{Total uranium in entering ore} = (0.0435)(33.60) = 1.4608 \text{ lb/hr}$$

$$\text{Uranium in by-product} = (0.0435)(0.4268) = 1.86 \times 10^{-2} \text{ lb/hr}$$

$$\text{Uranium in tailings pond} = 1.4608 \quad (1.86 \times 10^{-2}) + (6.52 \times 10^{-5}) + (1.0 \times 10^{-5}) = 1.4421 \text{ lb/hr}$$

$$^{238}\text{U} = (0.993)(1.4421) = 1.432 \text{ lb/hr}$$

$$^{235}\text{U} = 1.01 \times 10^{-2} \text{ lb/hr}$$

All of the ^{232}Th daughter products end up in the tailings pond except those emitted as dust, in the by-product, and as ^{228}Th in the product. The activity in the tailings pond is:

^{232}Th	1.216 lb/hr	$6.08 \times 10^{-5} \text{ Ci/hr}$
^{238}U	1.432 lb/hr	$2.17 \times 10^{-4} \text{ Ci/hr}$
^{235}U	$1.01 \times 10^{-2} \text{ lb/hr}$	$9.83 \times 10^{-6} \text{ Ci/hr}$
^{232}Th Daughters	Trace	$1.3328 \times 10^{-2} \text{ Ci/hr}$
^{238}U Daughters (13)	Trace	$2.82 \times 10^{-3} \text{ Ci/hr}$
^{235}U Daughters (10)	Trace	$9.83 \times 10^{-6} \text{ Ci/hr}$

D.9 GENERATED WASTES FROM CONWAY GRANITE MILL

Dust from Unloading, Crushing, and Grinding the Ore

This stream carries 454.5 lb/hr of airborne wastes, of which 2.4024×10^{-3} lb/hr are ^{232}Th , and shown in Figure D.9. The uranium content of the dust = $(0.25)(2.4024 \times 10^{-3}) = 6.006 \times 10^{-4}$ lb/hr. The uranium is split between ^{238}U and ^{235}U and the ratio is:

$$\left(\frac{0.993}{0.007}\right)\left(\frac{^{238}\text{U}}{^{235}\text{U}}\right)$$

There are 5.964×10^{-4} lb/hr ^{238}U and 4.2×10^{-6} lb/hr ^{235}U emitted.

The activity of the dust stream is:

^{232}Th	2.4024×10^{-3} lb/hr	1.201×10^{-7} Ci/hr
^{238}U	5.964×10^{-4} lb/hr	9.022×10^{-8} Ci/hr
^{235}U	4.2×10^{-6} lb/hr	4.087×10^{-9} Ci/hr
^{232}Th Daughters (9)	Trace	1.081×10^{-6} Ci/hr
^{238}U Daughters (13)	Trace	1.1728×10^{-6} Ci/hr
^{235}U Daughters (10)	Trace	9.022×10^{-7} Ci/hr

Drying and Packaging Dust

These processes release 0.029 lb/hr of airborne wastes, of which 0.01455 lb/hr are ^{232}Th ; the amount of uranium is 3.939×10^{-3} lb/hr; so $^{238}\text{U} = 3.912 \times 10^{-3}$ lb/hr and $^{235}\text{U} = 2.7 \times 10^{-5}$ lb/hr. The activity in the dust stream is:

^{232}Th	167.96 lb/hr	8.387×10^{-3} Ci/hr
^{238}U	36.49 lb/hr	5.520×10^{-3} Ci/hr
^{235}U	0.26 lb/hr	2.53×10^{-4} Ci/hr
^{232}Th Daughters(9)	Trace	7.548×10^{-2} Ci/hr
^{238}U Daughters (13)	Trace	7.176×10^{-2} Ci/hr
^{235}U Daughters (10)	Trace	2.53×10^{-3} Ci/hr

FIGURE D.9. Conway Granite Mill Flowsheet

FIGURE D.9. Legend: Flow Streams for Conway Granite Mill

1. 4545.45 tons/hr ore w/480 lb/hr ^{232}Th
2. 454.5 lb/hr w/ 2.4024×10^{-3} lb/hr ^{232}Th
3. 4545.22 tons/hr w/480 lb/hr ^{232}Th
4. 800 tons/hr
5. 72.72 tons/hr H_2SO_4
6. 5345.22 tons/hr w/480 lb/hr ^{232}Th
7. 1181.7 tons/hr H_2O
8. 727.28 tons/hr
9. 5799.46 tons/hr w/167.96 lb/hr ^{232}Th
10. 2908.8 tons/hr
11. 2908.98 tons/hr w/312.04 lb/hr ^{232}Th
12. 500 tons/hr amine solvent
13. 500.18 tons/hr w/312.04 lb/hr ^{232}Th
14. 63.63 tons/hr Na_2CO_3
15. 63.81 tons/hr w/312.04 lb/hr ^{232}Th
16. 2.73 tons/hr H_2SO_4
17. 909 lb/hr NH_3
18. 66.71 tons/hr w/23.999 lb/hr ^{232}Th
19. 574.24 lb/hr w/288.04 lb/hr ^{232}Th
20. 0.029 lb/hr w/ 1.452×10^{-2} lb/hr ^{232}Th
21. 574.21 lb/hr w/288.024 lb/hr ^{232}Th

Tailings to Return to Mine

In this stream, 5345.22 tons/hr are to be dewatered and returned to the mine for disposal. Of this, 167.96 lb/hr are ^{232}Th . The stream carries 36.75 lb/hr of uranium divided into two categories:

$$^{238}\text{U} = 36.49 \text{ lb/hr}$$

$$^{235}\text{U} = 0.26 \text{ lb/hr}$$

The activity in the stream is:

^{232}Th	167.96 lb/hr	8.387×10^{-3} Ci/hr
^{238}U	36.49 lb/hr	5.520×10^{-3} Ci/hr
^{235}U	0.26 lb/hr	2.53×10^{-4} Ci/hr
^{232}Th Daughters (9)	Trace	7.548×10^{-2} Ci/hr
^{238}U Daughters (13)	Trace	7.176×10^{-2} Ci/hr
^{235}U Daughters (10)	Trace	2.53×10^{-3} Ci/hr

The above waste stream is to be dewatered and returned to the mine. If it is necessary, lime may be added before dewatering in order to neutralize the waste stream. About 350 lb/hr of lime will be needed in order to completely neutralize the waste.

Liquid Waste To Tailings Pond

In this stream, 66.71 tons/hr are to be sent to the tailings pond for disposal; of this, 23.999 lb/hr are ^{232}Th . The stream also contains uranium in these amounts:

$$^{238}\text{U} = 5.2087 \text{ lb/hr}$$

$$^{235}\text{U} = 3.68 \times 10^{-2} \text{ lb/hr}$$

The activity in the stream is:

^{232}Th	23.999 lb/hr	1.1998×10^{-3} Ci/hr
^{238}U	5.2087 lb/hr	7.8791×10^{-4} Ci/hr
^{235}U	3.68×10^{-2} lb/hr	3.581×10^{-5} Ci/hr
^{232}Th Daughters (9)	Trace	1.0798×10^{-2} Ci/hr
^{238}U Daughters (13)	Trace	1.0243×10^{-2} Ci/hr
^{235}U Daughters (10)	Trace	3.581×10^{-4} Ci/hr

D.10 GENERATED WASTES FROM CONWAY GRANITE REFINERY

Waste Sludge

The waste sludge stream carries 663 lb/hr of sludge, which is 80% solids; of this, 5.72 lb/hr are ^{232}Th . The amount of uranium in the entering milled product is 13.6% of the total or 77.43 lb/hr. If the same ratio is assumed between Th and U in the waste sludge, the amount of uranium in the waste sludge is 1.55 lb/hr. The amount of ^{238}U = 1.54 lb and the amount of ^{235}U is 1.00×10^{-2} lb/hr. The activity in the waste sludge stream is:

^{232}Th	5.72 lb/hr	2.86×10^{-4} Ci/hr
^{238}U	1.55 lb/hr	2.34×10^{-4} Ci/hr
^{235}U	1.00×10^{-2} lb/hr	9.73×10^{-6} Ci/hr
^{232}Th Daughters (9)	Trace	2.574×10^{-3} Ci/hr
^{238}U Daughters (13)	Trace	3.048×10^{-3} Ci/hr
^{235}U Daughters (10)	Trace	9.73×10^{-5} Ci/hr

This waste sludge is already concentrated to 80% solids and can be disposed of by proper burial techniques at an approved site.

Liquid Waste to Tailings Pond

As shown in Figure D.10, the following streams and respective loads are sent to a tailings pond:

Dewatering Stream - 1216 lb/hr containing 0.308 lb/hr ^{232}Th with a total flow of 2.43 gpm.

Drying Stream - 56.85 lb/hr, mainly H_2O , with a total flow of 0.114 gpm.

Extraction and Scrubbing Stream - 1254 lb/hr containing 0.264 lb/hr of ^{232}Th with a total flow of 2.51 gpm.

Uranium Back Extraction and Scrubbing Stream - 318 lb/hr with no ^{232}Th and a total flow of 0.64 gpm.

Boildown and Evaporation Stream - 5351 lb/hr mainly H_2O , with a total flow of 1.07 gpm.

CONWAY GRANITE REFINERY

FIGURE D.10. Conway Granite Refinery Flowsheet

FIGURE D.10. Legend: Flow Streams for Conway Granite Refinery

1. 570 lb/hr w/285.9 lb/hr ^{232}Th
2. 299 lb/hr HNO_3
3. 491 lb/hr H_2O
4. 1360 lb/hr w/285.9 lb/hr ^{232}Th
5. 663 lb/hr w/5.72 lb/hr ^{232}Th
6. 697 lb/hr w/280.18 lb/hr ^{232}Th
7. 1367 lb/hr 4M HNO_3
8. 1367 lb/hr w/0.308 lb/hr ^{232}Th
9. 33 lb/hr NH_3
10. 1400 lb/hr w/0.308 lb/hr ^{232}Th
11. 1216 lb/hr w/0.308 lb/hr ^{232}Th
12. 184 lb/hr
13. 56.86 lb/hr H_2O
14. 127.14 lb/hr (70% U_3O_8)
15. 697 lb/hr w/279.87 lb/hr ^{232}Th
16. 557 lb/hr HNO_3
17. 1254 lb/hr w/0.264 lb/hr ^{232}Th
18. 6359 lb/hr
19. 6677 lb/hr w/279.606 lb/hr ^{232}Th
20. 6677 lb/hr of 0.1 HNO_3
21. 318 lb/hr
22. 6677 lb/hr w/279.606 lb/hr ^{232}Th
23. 5351 lb/hr H_2O
24. 1326 lb/hr w/279.606 lb/hr ^{232}Th
25. 74 lb/hr HNO_3
26. 87 lb/hr H_2O
27. 112.6 lb/hr oxalic acid
28. 1599.6 lb/hr w/279.606 lb/hr ^{232}Th
29. 288.9 lb/hr H_2O
30. 1070.9 lb/hr w/2.29 lb/hr ^{232}Th
31. 309.7 lb/hr Na_2CO_3
32. 1380.6 lb/hr w/2.29 lb/hr ^{232}Th
33. 817.6 lb/hr w/277.316 lb/hr ^{232}Th
34. 326 lb/hr H_2O
35. 581.6 lb/hr w/277.316 lb/hr ^{232}Th
36. 43.3 lb/hr O_2
37. 100.8 lb/hr H_2O and 205.8 lb/hr CO_2 w/5.72 lb/hr ^{232}Th
38. 5.66 lb/hr ^{232}Th
39. 307.7 lb/hr w/5.72 x 10^{-2} lb/hr ^{232}Th
40. 311.8 lb/hr w/271.60 lb/hr ^{232}Th

Plate-and-Frame Press Stream - 1380.6 lb/hr containing 2.29 lb/hr ^{232}Th with a total flow of 2.76 gpm.

Twin-Screw Dryer Stream - 236 lb/hr, mainly H_2O , with a total flow of 0.47 gpm.

The total amount sent to the tailings pond is 9812.46 lb/hr, of which 2.86 lb/hr is ^{232}Th . The total flow to the pond is 19.625 gpm. Uranium also enters the tailings pond in these amounts:

Uranium in tailings pond = $77.43 - 75.47 - 1.55 = 0.41$ lb/hr

$^{238}\text{U} = (0.993)(0.41) = 0.407$ lb/hr

$^{235}\text{U} = (0.007)(0.41) = 3.0 \times 10^{-2}$ lb/hr

The activity in the tailings pond is:

^{232}Th	2.86 lb/hr	1.43×10^{-4} Ci/hr
^{238}U	0.407 lb/hr	6.16×10^{-5} Ci/hr
^{235}U	3.0×10^{-3} lb/hr	2.92×10^{-6} Ci/hr
^{232}Th Daughters	Trace	1.122×10^{-1} Ci/hr
^{238}U Daughters	Trace	1.3682×10^{-1} Ci/hr
^{235}U Daughters	Trace	5.158×10^{-3} Ci/hr

Drying and Loading Dust

The drying and loading processes emit 100.8 lb/hr H_2O , 205.8 lb/hr CO_2 , and 5.72 lb/hr ^{232}Th into the dust stream. This stream is controlled by hoods connected to a 12,000-cfm bag filter unit and HEPA filters, which remove 99% of the dust. This system captures 5.66 lb/hr of ^{232}Th in solids. The other 0.0572 lb/hr of ^{232}Th is emitted to the atmosphere. The activity in the streams is:

^{232}Th (solid)	5.66 lb/hr	2.83×10^{-4} Ci/hr
^{228}Th (solid)	Trace	2.83×10^{-4} Ci/hr
^{232}Th (air)	0.0572 lb/hr	2.86×10^{-6} Ci/hr
^{228}Th (air)	Trace	2.86×10^{-6} Ci/hr

APPENDIX E

CAPITAL COSTS FOR BASELINE ENVIRONMENTAL CONTROL TECHNOLOGY

APPENDIX E: CAPITAL COSTS FOR BASELINE ENVIRONMENTAL CONTROL TECHNOLOGY

E.1 STOCKPILE REFINERY CAPITAL COSTS

Waste Sludge

The waste sludge will be hauled to a clay lined landfill pit using a small dump truck or a forklift using dumpsters. The pit will be approximately 2-1/2 acres in size on a 3-acre tract.

Grub and clear 3 acres	\$ 2,000
Excavate pit	68,600
Perimeter drainage	4,000
Finishing	4,000
Clay lining	<u>26,500</u>
Subtotal	105,100
20% Overhead	21,000
Truck and 2 dumpster hoppers	25,000
Land - 3 acres at \$2,000	<u>6,000</u>
Total Installed Cost	<u>\$157,100</u>

Refinery Tailings Pond

The tailings pond serves mainly as an evaporation pond because very little solids are contained in the liquid effluent. The pond will be approximately 4 acres in size and it will be lined with about 3 ft of clay.

Grub and clear 5 acres	\$ 3,300
Excavate pond	77,400
Perimeter drainage	4,000
Pump and pipes	2,800
Finishing and miscellaneous	4,000
Clay lining	<u>36,800</u>
Subtotal	128,300
20% Overhead	25,700
Land - 5 acres at \$2,000/acre	<u>10,000</u>
Total Installed Cost	<u>\$164,000</u>

Drying and Packaging Dust

The dust in this area is more radioactive and requires the state-of-the-art technology to control it. A baghouse filter and HEPA filter are used in series to collect the dust. An air demister unit is used to heat the bulk 6000 cfm airstream well above the dew point and keep the water content below saturation.

6000 cfm Dust Control

Baghouse filter =	$\$126,000 \left(\frac{6,000}{30,000} \right)^{0.85*}$	\$ 32,100
HEPA filter system		64,900
Demister unit		<u>6,700</u>
Total Installed Cost		<u>\$ 103,700</u>

*Note - Scaling factors utilize Lemhi Pass costs as a basis in this study unless noted otherwise.

Pond Beach Dust

A portable sprayer is used to periodically spray chemicals on the shores of the tailings pond.

Equipment cost is estimated at	<u>\$ 4,000</u>
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Tailings Pond Cover

At the conclusion of the refinery's life the pond will be allowed to evaporate. The residual solids will be covered by a minimum of 6 ft of earth and 6 in. of rock.

6 ft earth and 6 in. rock cover =	$920,000 \left(\frac{4}{100} \right)^{0.8}$	<u>\$ 70,100</u>
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E.2. LEMHI PASS CAPITAL COSTS

Mine Water

Use a 2-acre settling pond located on 3-acre tract.

Grub and clear 3 acres	\$ 2,000
Excavate pond	19,300
Trenches	1,500
Perimeter drainage	2,000
Finishing operations	<u>2,000</u>
Subtotal	26,800
20% Overhead	5,400
Land - 3 acres at \$1,000/acre	<u>3,000</u>
Total Installed Cost	<u>\$ 35,200</u>

Controlled Mine Dust

Dust is sufficiently dilute, therefore, no waste control equipment is required.

300,000 cfm ventilation system, no control equipment

Total Installed Cost	<u>\$ 0</u>
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Uncontrolled Mine Dust

Water tank truck w/sprayer attachments	30,000
Storage pile barriers	<u>15,000</u>
Total Installed Cost	<u>\$ 45,000</u>

Loading, Crushing, and Grinding Dust

26,000 cfm cyclone w/fans	
Total Installed Cost	<u>\$ 19,900</u>

Drying and Ignition Dust

21,000 cfm wet impingement scrubber w/fans and pumps

Total Installed Cost \$ 39,900

Packaging Dust

4,000 cfm baghouse filter w/fans

Total Installed Cost \$ 22,700

Tailings Pond

100-acre clay core dam and reservoir \$2,401,000

Distribution system, pumps, pipeline 220,000

Recycling system, pumps, pipe and 1-acre settling pond 320,000

Land - 125 acres at \$1,000/acre 125,000

Total Installed Cost \$3,066,000

Tailings Pond Beach Dust

Chemical spraying equipment (portable)

Total Installed Cost \$ 20,000

Tailings Pond Cover

1 ft earth cover at \$1,200/acre \$ 120,000

6 in. rock cover at \$2,000/acre 200,000

Total Installed Cost \$ 320,000

E.3. HALL MOUNTAIN CAPITAL COSTS

Mine Water

(250 gpm, ^{232}Th level below standard; use 1-acre settling pond on 1-1/2-acre tract)

1-acre Settling Pond

Settling pond one-half size of Lemhi Pass Pond

$$\therefore \$35,200 \left(\frac{250 \text{ gpm}}{500 \text{ gpm}} \right)^{0.7} = \text{Total Installed Cost} \quad \underline{\underline{\$ 21,700}}$$

Controlled Mine Dust

Same as Lemhi Pass except ventilation air of $160,000 \text{ ft}^3/\text{min}$ is required and ^{232}Th peak level is $2.78 \times 10^{-11} \mu\text{Ci/ml}$. No waste control equipment is needed.

Total Installed Cost \$ 0

Uncontrolled Mine Dust

Same as Lemhi Pass except smaller spray equipment and barriers are used.

Water tank truck w/sprayer attachments	\$ 17,300
Storage pile barriers	<u>8,700</u>
Total Installed Cost	<u><u>\$ 26,000</u></u>

Loading, Crushing and Grinding Dust

Same as Lemhi Pass except a smaller 18,000 cfm cyclone is used.

18,000 cfm cyclone w/fans	
Total Installed Cost	<u><u>\$ 13,500</u></u>

Drying and Ignition Dust

25,000 cfm wet impingement scrubber w/fans and pumps

Total Installed Cost	<u><u>\$ 46,200</u></u>
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Packaging Dust

4,400 cfm baghouse filter w/fan

Total Installed Cost \$ 24,700

Tailings Pond

Use 15-acre clay core dam and reservoir. Recycle water.

15-acre clay core dam and reservoir \$ 636,000

Distribution system, pump, pipes 172,000

Recycling system 137,000

Land - 25 acres at \$1,000/acre 25,000

Total Installed Cost \$ 970,000

Tailings Pond Beach Dust

Same as Lemhi Pass except smaller equipment used.

Chemical spraying equipment (portable)

Total Installed Cost = \$20,000 $\left(\frac{400}{1000}\right)^{0.6}$ \$ 11,500

Tailings Pond Cover

Same as Lemhi Pass except scaled down.

1 ft earth and 6 in. rock cover

Total Installed Cost = \$320,000 $\left(\frac{15}{100}\right)^{0.8}$ \$ 70,100

E.4 WET MOUNTAIN CAPITAL COSTS

Mine Water

Same as Hall Mt. Flow = 250 gpm. The ^{232}Th level is the same. Use 1-acre settling pond on 1-1/2-acre tract.

Total Installation Cost	<u>\$ 21,700</u>
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Controlled Mine Dust

Use 140,000 cfm ventilation for peak level of $2.43 \times 10^{-11} \mu\text{Ci/ml}$. No waste control equipment is needed.

Total Installation Cost	<u>\$ 0</u>
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Uncontrolled Mine Dust

Same as Lemhi and Hall Mt. except smaller equipment is used.

Water truck w/sprayer attachments	\$ 16,000
Storage pile barriers	<u>8,000</u>
Total Installation Cost	<u>\$ 24,000</u>

Loading, Crushing and Grinding Dust

Same as Lemhi and Hall Mt. except different size cyclone is needed.

Use 13,000 cfm

Installed Cost = $\$22,500 \left(\frac{13,000}{30,000} \right)^{0.85}$	<u>\$ 11,100</u>
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Drying and Ignition Dust

Same as Lemhi and Hall Mt. except different size scrubber is needed. Use 20,000 cfm wet impingement scrubber.

Installed Cost = $54,000 \left(\frac{20,000}{30,000} \right)^{0.85}$	<u>\$ 38,300</u>
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Packaging Dust

Use 3,500 cfm baghouse filter.

$$\text{Installed Cost} = 126,000 \left(\frac{3,500}{30,000} \right)^{0.85} \quad \underline{\underline{\$ \quad 20,300}}$$

Tailings Pond

Use 14-acre clay core dam and reservoir. Recycle water.

14-acre clay core dam and reservoir	\$ 606,300
Distribution system, pumps, pipes	153,400
Recycling system	118,500
Land - 24 acres at \$1,000/acre	<u>24,000</u>
Total Installed Cost	<u><u>\$ 902,200</u></u>

Tailings Pond Beach Dust

Same as Lemhi Pass except smaller equipment is used.

$$\text{Installed cost} = 20,000 \left(\frac{350}{1000} \right)^{0.6} \quad \underline{\underline{\$ \quad 10,700}}$$

Tailings Pond Cover

Same as Lemhi, except scaled down.

1 ft earth and 6 in. rock cover

$$\text{Installed cost} = 320,000 \left(\frac{14}{100} \right)^{0.8} \quad \underline{\underline{\$ \quad 66,400}}$$

E.5 PALMER, MICHIGAN, CAPITAL COSTS

Mine Water

Mine water will pass through a 3-acre settling pond and be pumped to the mill/refinery complex to be used as process water. Excess water is discharged into surface waters.

Grub and clear 4 acres	\$ 2,700
Excavate pond	46,500
Trenches	3,600
Drainage around pond	7,000
Pumps	52,500
Piping	<u>79,200</u>
Subtotal	191,500
20% Overhead	38,300
Land - 4 acres at \$1,500/acre	<u>6,000</u>
Total Installed Cost	<u>\$ 235,800</u>

Uncontrolled Mine Dust

Procure spraying equipment and install wind barriers.

Water tank truck, sprayer w/attachments	\$ 50,000
Miscellaneous, spray hoses, etc.	10,000
Storage pile barriers	96,000
Total Installed Costs	<u>\$ 156,000</u>

Mill Unloading, Crushing, and Grinding Dust

Four 50,000 cfm cyclones will be used to collect this dust.

Four 50,000 cfm cyclones at \$34,725

Installed Cost = 34,725 (4) \$ 138,900

Drying, Magnetic Separation, and Loading Dust

A 60,000 cfm wet impingement scrubber will be used to collect dust from these operations.

Installed Cost \$ 108,000

Mill Separation and Dewatering Liquid Waste

A 200-acre clay lined tailings pond will be used for settling out the solids. A distribution system will be used to spread the solids evenly throughout the pond. A recycling system, which consists of pumps, pipes and a small auxiliary settling pond, will be used to return water to the mill for reuse.

Clay lined pond = $3,416,000 \left(\frac{200}{100} \right)^{0.7}$ \$5,551,000

Distribution system = $320,000 \left[\frac{(22)(900)}{5803} \right]^{0.7}$ 755,500

Recycle system = $220,000 \left(\frac{2372}{600} \right)^{0.7}$ 575,800

Land - 225 acres at \$1,500/acre 337,500

Total Installed Cost \$7,219,800

Refinery Unloading and Grinding Dust

A 10,000 cfm baghouse filter will be required.

Installed Cost = $126,000 \left(\frac{10,000}{30,000} \right)^{0.85}$ \$ 49,500

Refinery Ignition and Drying Dust

A 16,000 cfm low energy venturi scrubber will be used to collect the dust.

Installed Cost	<u>\$ 36,900</u>
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Packaging Dust

A 3,000 cfm baghouse filter will be used.

Installed Cost	<u>\$ 17,800</u>
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By-Product Recovery Dust

A 24,000 cfm wet impingement scrubber will be used.

Installed Cost	<u>\$ 44,700</u>
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Refinery Tailings Pond

A 20-acre pond lined with 3 ft of clay will be used to collect the solids and recycle the water to the refinery.

20-acre clay core dam and reservoir	\$ 570,600
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Distribution system = $\left(320,000\right)\left(0.5\right)\left(\frac{4492}{5803}\right)^{0.7}$	128,700
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Recycling system = $\left(220,000\right)\left(\frac{748}{600}\right)^{0.7}$	256,700
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Land = 25 acres at \$1500/acre	<u>37,500</u>
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Total Installed Cost	<u>\$ 993,500</u>
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Refinery Tailings Pond Beach Dust

Portable chemical spraying equipment will be used periodically to tie down dust on the shore.

Installation and Equipment Cost is	<u>\$ 6,500</u>
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Refinery Tailings Pond Cover

After the refinery is permanently shut down a cover consisting of 6 ft of earth and 6 in. rock will be used.

Estimated Cost

\$ 253,900

E.6 BALD MOUNTAIN CAPITAL COSTS

Mine Water

A 2-acre settling pond with a pump and piping for transferring the water to the mill/refinery complex will be used for the base technology case.

Grub and clear 3 acres	\$ 2,000
Excavate pond	35,000
Trenches	2,400
Drainage around pond	4,500
Pumps	39,500
Piping	<u>59,700</u>
Subtotal	143,100
20% Overhead	28,600
Land - 3 acres at \$1,000/acre	<u>3,000</u>
Total Installed Cost	<u>\$ 174,700</u>

Uncontrolled Mine Dust

Same methods as Palmer, Michigan. Cost is as follows:

Water tank truck w/attachments	\$ 40,000
Miscellaneous	7,000
Storage pile barriers	<u>47,400</u>
Total	<u>\$ 94,400</u>

Mill Unloading, Crushing, and Grinding Dust

One 50,000 cfm cyclone will be used for these operations.

Installation Cost	<u>\$ 34,700</u>
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Drying, Magnetic Separation, and Loading Dust

A 30,000 cfm wet impingement scrubber will be used.

Installation Cost	<u>\$ 54,000</u>
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Mill Separation and Dewatering Liquid Waste

A 40-acre clay lined pond will be used for settling out the solids. The liquid will be recycled through a settling pond and reused in the mill.

Clay lined pond = $\left(3,416,000\right)\left(\frac{40}{100}\right)^{0.7}$	\$1,798,700
Distribution system = $\left(320,000\right)\left(\frac{4767}{5803}\right)^{0.7}$	278,900
Recycle system = $\left(220,000\right)\left(\frac{600}{600}\right)^{0.7}$	220,000
Land = 50 acres at \$1,000/acre	<u>50,000</u>
Total Installed Cost	<u>\$2,347,600</u>

Refinery Unloading and Grinding Dust

A 10,000 cfm cyclone is used.

Installation Cost	<u>\$ 8,800</u>
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Refinery Ignition and Drying Dust

A 6,000 cfm low energy venturi scrubber is used.

Installed Cost	<u>\$ 16,000</u>
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Packaging Dust

A 1,200 cfm baghouse filter is used.

Installed Cost	<u>\$ 8,200</u>
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By-Product Recovery Dust

A 15,000 cfm wet impingement scrubber is used.

Installed Cost	<u>\$ 30,000</u>
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Refinery Tailings Pond

A 6-acre clay lined pond is used to collect the solids and evaporate the liquid wastes. No recycle system is used.

6-acre clay core dam and reservoir	\$ 201,300
Land - 8 acres at \$1,000/acre	<u>8,000</u>
Total Installed Cost	<u>\$ 209,300</u>

Tailings Pond Beach Dust

A portable system will be used.	<u>\$ 4,000</u>
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Tailings Pond Cover

A 6 ft earth with 6 in. rock cover will be used.	<u>\$ 96,900</u>
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E.7 CONWAY GRANITE CAPITAL COSTS

Mine Water

A settling pond of about 4 acres is required. The water is subsequently pumped to the mill where large quantities of water are needed. Excess water can be discharged into surface waters.

$$\text{4-acre pond} = 71,800 \left(\frac{2000}{1500} \right)^{0.7*} \quad \$ \quad 87,800$$

$$\text{Pump and piping} = 158,000 \left(\frac{2000}{1500} \right)^{0.7*} \quad 193,200$$

$$\text{Land - 6 acres at \$2,000/acre} \quad \underline{12,000}$$

$$\text{Total Installed Cost} \quad \underline{\underline{\$ \quad 293,000}}$$

*Note - Palmer, Mich costs are basis.

Uncontrolled Mine Dust

Procure spraying equipment and install wind barriers.

$$\text{Water tank truck and auxilliary spraying equipment} \quad \$ \quad 60,000$$

$$\text{Miscellaneous} \quad 15,000$$

$$\text{Storage pile barriers} \quad \underline{150,000}$$

$$\text{Installation Cost} \quad \underline{\underline{\$ \quad 225,000}}$$

Unloading, Crushing and Grinding Dust at Mill

Two 50,000 cfm cyclones will be used to collect this dust.

$$2 \text{ cyclones at } \$34,725$$

$$\text{Installed Cost} = 34,725(2) \quad \underline{\underline{\$ \quad 69,500}}$$

Mill Drying and Packaging Dust

Radioactivity level of this dust is relatively low. A 30,000 cfm wet impingement scrubber is used.

Installation Cost	<u>\$ 54,000</u>
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Mill Tailings Pond

A 20-acre clay lined pond is used to collect the solids by settling. The recycle water is passed through an auxilliary settling pond before being returned to the mill.

20-acre clay core dam and reservoir	\$ 686,800
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Distribution system = $\left(320,000\right)\left(\frac{1467}{5803}\right)^{0.7} (0.5)$	61,100
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Recycle system = $\left(220,000\right)\left(\frac{224}{600}\right)^{0.7}$	110,400
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Land - 25 acres at \$2,000/acre	<u>50,000</u>
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Total Installed Cost	<u>\$ 908,300</u>
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Refinery Waste Sludge

The sludge will be handled just the same as the stockpile refinery sludge. Sludge will be trucked to a 2-1/2-acre clay lined pit for landfilling.

Installation Cost = $\$157,100 \left(\frac{350}{308}\right)$	<u>\$ 178,500</u>
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Refinery Tailings Pond

A 10-acre clay lined tailings pond is used with no recycle capability.

10-acre clay core dam and reservoir	\$ 300,800
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Land - 13 acres at \$2,000/acre	<u>26,000</u>
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Total Installed Cost	<u>\$ 326,800</u>
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Refinery Drying and Packaging Dust

Same as stockpile refinery except 12,000 cfm baghouse filters and HEPA filters are required in series.

Baghouse filters	\$ 57,800
HEPA filters	117,000
Demister	<u>12,000</u>
Installed Cost	<u>\$ 186,800</u>

Refinery Pond Beach Dust

A portable sprayer is used periodically to spray chemicals on the pond shore.

Installed Cost	<u>\$ 4,000</u>
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Refinery Pond Cover

At decommissioning a 6 ft earth and 6 in. rock cover will be placed over the residual solids.

6 ft earth and 6 in. rock installed	<u>\$ 145,800</u>
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APPENDIX F
ANNUAL COSTS FOR BASELINE TECHNOLOGY

APPENDIX F: ANNUAL COSTS FOR BASELINE TECHNOLOGY

E.1 STOCKPILE REFINERY CAPITAL COSTS

Waste Sludge

Truck to clay lined landfill onsite	
Capital charge = $(0.2338)(157,100)$	\$ 36,700
Land and Working Capital Charge (L&WCC) = $(0.05)(36,700)$	1,800
Operations = $(616 \text{ mh})(20.13)$	12,400
Maintenance = $(0.03)(157,100)$	4,700
Miscellaneous and Fuel	2,000
Total	<u>\$ 57,600</u>

Refinery Tailings Pond

4-acre clay lined pond, no recycle	
Capital charge = $(0.2338)(164,000)$	\$ 38,300
L&WCC = $(0.05)(38,300)$	1,900
Operations = $(50 \text{ mh})(20.13)$	1,000
Maintenance = $(0.01)(164,000)$	1,600
Supplies and miscellaneous	300
Total	<u>\$ 43,100</u>

Drying and Packaging Dust

6,000 cfm baghouse and HEPA filters w/conditioning	
- Baghouse filter	
Capital charge = $(0.2338)(32,100)$	\$ 7,500
L&WCC = $(0.05)(7,500)$	400
Operations cost	1,000
Maintenance	1,200
Miscellaneous	900
Power	2,400
Replacement bags	1,300
Subtotal	<u>\$ 14,700</u>

- HEPA Filter

Capital charge = $(0.2338)(64,900)$	\$ 15,200
L&WCC = $(0.05)(15,200)$	800
Operating Cost	1,000
Maintenance	2,400
Miscellaneous	1,300
Power	700
Replacement filters	<u>4,900</u>
Subtotal	<u>26,300</u>

- Conditioner, 1,000 cfm

Capital charge = $(0.2338)(6,700)$	\$ 1,600
L&WCC = $(0.05)(1,600)$	100
Operations = $(0.02)(6,700)$	100
Maintenance = $(0.03)(6,700)$	200
Miscellaneous	500
Power	<u>2,000</u>
Subtotal	<u>\$ 4,500</u>

Total Annual Cost = \$14,700

+26,300

+ 4,500 = \$45,500

Tailings Pond Beach Dust

Spraying operations

Capital charge = $(0.2338)(4,000)$	\$ 900
L&WCC = $(0.05)(900)$	100
Operations = $(50 \text{ mh})(20.13)$	1,000
Maintenance	200
Miscellaneous and Chemicals	<u>200</u>
Total	<u>\$ 2,400</u>

Tailings Pond Cover

6 ft earth w/6 in. rock cover

Sinking Fund = $(0.00976)(70,100)$	<u>\$ 700</u>
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F.2 LEMHI PASS ANNUAL COSTS

Mine Water Settling Pond

Capital charge = $(0.2441)(35,200)$	\$ 8,600
L&WCC = $(0.05)(8,600)$	400
Operations and Maintenance = $(0.06)(35,200)$	<u>2,100</u>
Total	<u>\$ 11,100</u>

Controlled Mine Dust

None	<u>\$ 0</u>
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Uncontrolled Dust

Spraying Operation

Capital charge = $(0.2441)(30,000)$	\$ 7,300
L&WCC = $(0.05)(7,300)$	400
Operators = $(16 \frac{mh}{wk})(52 \text{ wk})(20.13)$	16,700
Maintenance = $(0.06)(30,000)$	1,800
Fuel and supplies = $(100,000 \text{ kW-hr})(0.03)$	<u>3,000</u>
Subtotal	<u>\$ 29,200</u>

Storage Pile Barriers

Capital charge = $(0.2336)(15,000)$	\$ 3,500
L&WCC = $(0.05)(3,500)$	200
Maintenance = $(0.02)(15,000)$	300
Miscellaneous	<u>1,000</u>
Subtotal	<u>\$ 5,000</u>
Total = $\$29,200 + 5,000 =$	<u><u>\$34,200</u></u>

Loading, Crushing, and Grinding Dust

Cyclone

Capital charge = $(0.2336)(19,900)$	\$ 4,600
L&WCC = $(0.05)(4,600)$	200
Operations = $(65 \text{ mh})(20.13)$	1,300
Maintenance = $(0.03)(19,900)$	600
Miscellaneous	900
Power = $(133,300 \text{ kW-hr})(0.03)$	4,000
Total	<u>\$ 11,600</u>

Drying and Ignition Dust

Wet impingement scrubber

Capital charge = $(0.2336)(39,900)$	\$ 9,300
L&WCC = $(0.05)(9,300)$	500
Operations = $(110 \text{ mh})(20.13)$	2,200
Maintenance = $(0.03)(39,900)$	1,200
Miscellaneous	1,800
Power = $(180,000 \text{ kW-hr})(0.03)$	5,400
Total	<u>\$ 20,400</u>

Packaging Dust

Baghouse filter

Capital charge = $(0.2336)(22,700)$	\$ 5,300
L&WCC = $(0.05)(5,300)$	300
Operations = $(55 \text{ mh})(20.13)$	1,100
Maintenance = $(0.03)(22,700)$	700
Miscellaneous	500
Power = $(43,300 \text{ kW-hr})(0.03)$	1,300
Bag replacement	700
Total	<u>\$ 9,900</u>

Tailings Pond

100-acre clay core dam and reservoir and recycle

Capital charge = $(0.2336)(3,066,000)$	\$ 716,200
L&WCC = $(0.05)(716,200)$	35,800
Operations = $(2,250 \text{ mh})(20.13)$	45,300
Maintenance manpower = $(4,000 \text{ mh})(20.13)$	80,500
Maintenance parts and supplies	12,100
Miscellaneous	9,000
Power = $(483,300 \text{ kW-hr})(0.03)$	14,500
Total	<u>\$ 913,400</u>

Tailings Pond Beach Dust

Spraying operations

Capital charge = $(0.2336)(20,000)$	\$ 4,700
L&WCC = $(0.05)(4,700)$	200
Operations = $(832 \text{ mh})(20.13)$	16,700
Maintenance = $(0.06)(20,000)$	1,200
Miscellaneous, chemicals, etc.	3,200
Total	<u>\$ 26,000</u>

Tailings Pond Cover

1 ft earth and 6 in. rock cover

Sinking Fund = $(0.00306)(320,000)$	<u>\$ 1,000</u>
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F.3 HALL MOUNTAIN ANNUAL COSTS

Mine Water

Settling pond, 1 acre

Capital charge = $(0.3681)(21,700)$ \$ 8,000

L&WCC = $(0.05)(8,000)$ 400

Operation and maintenance = $(0.06)(21,700)$ 1,300

Total \$ 9,700

Controlled Mine Dust

None \$ 0

Uncontrolled Dust

Spraying

Capital charge = $(0.3681)(17,300)$ \$ 6,400

L&WCC = $(0.05)(6,400)$ 300

Operations = $(475 \text{ mh})(20.13)$ 9,600

Maintenance = $(0.06)(17,300)$ 1,000

Fuel and supplies 1,200

Subtotal 18,500

Storage pile barriers

Capital charge = $(0.3681)(8,700)$ \$ 3,200

L&WCC = $(0.05)(3,200)$ 200

Operations 0

Maintenance = $(0.02)(8,700)$ 200

Miscellaneous 600

Subtotal \$ 4,200

Total = $\$18,500 + 4,200 = \underline{\underline{\$22,700}}$

Loading, Crushing, and Grinding Dust

Cyclone, 18,000 cfm

Capital charge = $(0.3681)(13,500)$	\$ 5,000
L&WCC = $(0.05)(5,000)$	300
Operations = $(50 \text{ mh})(20.13)$	1,000
Maintenance = $(0.03)(13,500)$	400
Miscellaneous	700
Power = $(93,300 \text{ kW-hr})(0.03)$	<u>2,800</u>
Total	<u>\$ 10,200</u>

Drying and Ignition Dust

25,000 cfm wet impingement scrubber

Capital charge = $(0.3681)(46,200)$	\$ 17,000
L&WCC = $(0.05)(17,000)$	900
Operations = $(130 \text{ mh})(20.13)$	2,600
Maintenance = $(0.03)(46,200)$	1,400
Miscellaneous	2,100
Power = $(216,700 \text{ kW-hr})(0.03)$	<u>6,500</u>
Total	<u>\$ 30,500</u>

Packaging Dust

4,400 cfm baghouse filter

Capital charge = $(0.3681)(24,700)$	\$ 9,100
L&WCC = $(0.05)(9,100)$	500
Operations = $(60 \text{ mh})(20.13)$	1,200
Maintenance = $(0.03)(24,700)$	700
Miscellaneous	600
Power = $(46,700 \text{ kW-hr})(0.03)$	1,400
Bag replacement	<u>800</u>
Total	<u>\$ 14,300</u>

Tailings Pond

15-acre clay core dam and reservoir and recycle

Capital charge = $(0.3681)(970,000)$	\$ 357,000
L&WCC = $(0.05)(357,000)$	17,900
Operations = $(1,500 \text{ mh})(20.13)$	30,200
Maintenance = $(0.03)(970,000)$	29,100
Miscellaneous	7,000
Power = $(283,300 \text{ kW-hr})(0.03)$	8,500
Total	<u>\$ 449,700</u>

Tailings Pond Beach Dust

Spraying operations

Capital charge = $(0.3681)(11,500)$	\$ 4,200
L&WCC = $(0.05)(4,200)$	200
Operations = $(475 \text{ mh})(20.13)$	9,600
Maintenance = $(0.06)(11,500)$	700
Miscellaneous, chemicals, etc.	1,300
Total	<u>\$ 16,000</u>

Tailings Pond Cover

1 ft earth and 6 in. rock cover

Sinking fund = $(0.14832)(70,100)$	<u>\$ 10,400</u>
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F.4 WET MOUNTAIN ANNUAL COSTS

Mine Water

Settling Pond

Capital charge = $(0.3681)(21,700)$	\$ 8,000
L&WCC = $(0.05)(8,000)$	400
Operations and maintenance = $(0.06)(21,700)$	<u>1,300</u>
Total	<u>\$ 9,700</u>

Controlled Mine Dust

None	<u>\$ 0</u>
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Uncontrolled Dust

Spraying

Capital charge = $(0.3681)(16,000)$	\$ 5,900
L&WCC = $(0.05)(5,900)$	300
Operations = $(440 \text{ mh})(20.13)$	8,900
Maintenance = $(0.06)(16,000)$	1,000
Fuel and supplies	<u>1,100</u>
Subtotal	<u>\$ 17,200</u>

Storage pile barriers

Capital charge = $(0.3681)(8,000)$	\$ 2,900
L&WCC = $(0.05)(2,900)$	100
Operations	0
Maintenance = $(0.02)(8,000)$	200
Miscellaneous	<u>500</u>
Subtotal	<u>\$ 3,700</u>

Total = $\$17,200 + 3,700 = \underline{\underline{\$20,900}}$

Loading, Crushing, and Grinding Dust

Cyclone, 13,000 cfm

Capital charge = $(0.3681)(11,100)$	\$ 4,100
L&WCC = $(0.05)(4,100)$	200
Operations = $(35 \text{ mh})(20.13)$	700
Maintenance = $(0.03)(11,100)$	300
Miscellaneous	500
Power = $(66,700 \text{ kW-hr})(0.03)$	<u>2,000</u>
Total	<u>\$ 7,800</u>

Drying and Ignition Dust

Wet impingement scrubber, 20,000 cfm

Capital charge = $(0.3681)(38,300)$	\$ 14,100
L&WCC = $(0.05)(14,100)$	700
Operations = $(105 \text{ mh})(20.13)$	2,100
Maintenance = $(0.03)(38,300)$	1,100
Miscellaneous	1,800
Power = $(173,300 \text{ kW-hr})(0.03)$	<u>5,200</u>
Total	<u>\$ 25,000</u>

Packaging Dust

Baghouse filter, 3,500 cfm

Capital charge = $(0.3681)(20,300)$	\$ 7,500
L&WCC = $(0.05)(7,500)$	400
Operations = $(50 \text{ mh})(20.13)$	1,000
Maintenance = $(0.03)(20,300)$	600
Miscellaneous	500
Power = $(40,000 \text{ kW-hr})(0.03)$	1,200
Bag replacement	<u>600</u>
Total	<u>\$ 11,800</u>

Tailings Pond

14-acre clay core dam and reservoir and recycle

Capital charge = $(0.3681)(902,200)$	\$ 332,100
L&WCC = $(0.05)(332,100)$	16,600
Operations = $(1,400 \text{ mh})(20.13)$	28,200
Maintenance = $(0.03)(902,200)$	27,100
Miscellaneous	6,000
Power = $(230,000 \text{ kW-hr})(0.03)$	<u>6,900</u>
Total	<u>\$ 416,900</u>

Tailings Pond Beach Dust

Spraying operations

Capital charge = $(0.3681)(10,700)$	\$ 3,900
L&WCC = $(0.05)(3,900)$	200
Operations = $(440 \text{ mh})(20.13)$	8,900
Maintenance = $(0.06)(10,700)$	600
Miscellaneous, chemicals, etc.	<u>1,100</u>
Total	<u>\$ 14,700</u>

Tailings Pond Cover

1 ft earth and 7 in. rock cover

Sinking fund = $(0.14832)(66,400)$	<u>\$ 9,800</u>
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F.5 PALMER, MICHIGAN, ANNUAL COSTS

Mine Water

3-acre settling pond and pumping system

Capital charge = $(0.2338)(235,800)$	\$ 55,100
L&WCC = $(0.05)(55,100)$	2,800
Operations = $(235 \text{ mh})(20.13)$	4,700
Maintenance = $(0.03)(235,800)$	7,100
Power = $(1,033,000 \text{ kW-hr})(0.03)$	31,000
Total	<u>\$ 100,700</u>

Uncontrolled Dust

Spray equipment and storage pile barriers

Capital charge = $(0.2338)(156,000)$	\$ 36,500
L&WCC = $(0.05)(36,500)$	1,800
Operations = $(1,560 \text{ mh})(20.13)$	31,400
Maintenance = $(0.03)(156,000)$	4,700
Fuel, chemicals and miscellaneous	30,000
Total	<u>\$ 104,400</u>

Unloading and Crushing Dust

4-50,000 cfm cyclones

Capital charge = $(0.2338)(138,900)$	\$ 32,500
L&WCC = $(0.05)(32,500)$	1,600
Operations = $(545 \text{ mh})(20.13)$	11,000
Maintenance	5,000
Miscellaneous	7,400
Power = $(1,173,000 \text{ kW-hr})(0.03)$	35,200
Total	<u>\$ 87,700</u>

Drying, Magnetic Separation, and Loading Dust

2-30,000 cfm wet impingement scrubbers	
Capital charge = $(0.2338)(108,000)$	\$ 25,300
L&WCC = $(0.05)(25,300)$	1,300
Operations = $(412 \text{ mh})(20.13)$	8,300
Maintenance	4,400
Miscellaneous	6,900
Power = $(683,000 \text{ kW-hr})(0.03)$	<u>20,500</u>
Total	<u>\$ 66,700</u>

Separation and Dewatering Liquid Waste

200-acre clay lined pond w/recycle	
Capital charge = $(0.2338)(7,219,800)$	\$1,688,000
L&WCC = $(0.05)(1,688,000)$	84,400
Operations = $(6,000 \text{ mh})(20.13) \left(\frac{330}{240}\right)$	166,100
Maintenance = $(8,000 \text{ mh})(20.13) \left(\frac{330}{240}\right)$	221,400
Supplies, parts, etc.	55,000
Power = $(2,627,000 \text{ kW-hr})(0.03)$	<u>78,800</u>
Total	<u>\$2,293,700</u>

Unloading and Grinding Dust

10,000 cfm baghouse filter	
Capital charge = $(0.2338)(49,500)$	\$ 11,600
L&WCC = $(0.05)(11,600)$	600
Operations = $(160 \text{ mh})(20.13)$	3,200
Maintenance = $(0.04)(49,500)$	2,000
Miscellaneous	1,600
Power = $(147,000 \text{ kW-hr})(0.03)$	4,400
Bag replacement	<u>2,300</u>
Total	<u>\$ 23,900</u>

Ignition and Drying Dust

16,000 cfm low energy venturi scrubber

Capital charge = $(0.2338)(36,900)$	\$ 8,600
L&WCC = $(0.05)(8,600)$	400
Operations = $(180 \text{ mh})(20.13)$	3,600
Maintenance = $(0.04)(36,900)$	1,500
Miscellaneous	2,400
Power = $(287,000 \text{ kW-hr})(0.03)$	8,600
Total	<u>\$ 25,100</u>

Packaging Dust

3,000 cfm baghouse filter

Capital charge = $(0.2338)(17,800)$	4,200
L&WCC = $(0.05)(4,200)$	200
Operations = $(45 \text{ mh})(20.13)$	900
Maintenance	500
Miscellaneous	400
Power = $(33,300 \text{ kW-hr})(0.03)$	1,000
Bag replacement	500
Total	<u>\$ 7,700</u>

By-Product Recovery Dust

24,000 cfm wet impingement scrubber

Capital charge = $(0.2338)(44,700)$	\$ 10,400
L&WCC = $(0.05)(10,400)$	500
Operations = $(164 \text{ mh})(20.13)$	3,300
Maintenance	1,800
Miscellaneous	2,700
Power = $(273,000 \text{ kW-hr})(0.03)$	8,200
Total	<u>\$ 26,900</u>

Liquid Waste to Tailings Pond

20-acre pond w/3 ft clay liner w/recycle

Capital charge = $(0.2338)(993,500)$	\$ 232,300
L&WCC = $(0.05)(232,300)$	11,600
Operations = $(3,000 \text{ mh})(20.13)$	60,400
Maintenance = $(4,000 \text{ mh})(20.13)$	80,500
Supplies, parts, etc.	20,000
Power = $(603,000 \text{ kW-hr})(0.03)$	18,100
Total	<u>\$ 422,900</u>

Tailings Pond Beach Dust

Spraying Operations

Capital charge = $(0.2338)(6,500)$	\$ 1,500
L&WCC = $(0.05)(1,500)$	100
Operations = $(156 \text{ mh})(20.13)$	3,200
Maintenance = $(0.06)(6,500)$	400
Miscellaneous, chemicals, etc.	600
Total	<u>\$ 5,800</u>

Tailings Pond Cover

6 ft earth w/6 in. rock cover

Sinking fund = $(0.00976)(253,900)$	<u>\$ 2,500</u>
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F.6 BALD MOUNTAIN ANNUAL COSTS

Mine Water

2-acre settling pond and pumping system

Capital charge = $(0.2668)(174,700)$	\$ 46,600
L&WCC = $(0.05)(46,600)$	2,300
Operations = $(175 \text{ mh})(20.13)$	3,500
Maintenance = $(0.03)(174,700)$	5,200
Power = $(690,000 \text{ kW-hr})(0.03)$	20,700
Total	<u>\$ 78,300</u>

Uncontrolled Dust

Spraying and storage pile barriers

Capital charge = $(0.2668)(94,400)$	\$ 25,200
L&WCC = $(0.05)(25,200)$	1,300
Operations = $(1,090 \text{ mh})(20.13)$	22,000
Maintenance = $(0.03)(94,400)$	2,800
Fuel, supplies, miscellaneous	20,000
Total	<u>\$ 71,300</u>

Unloading and Crushing Dust

50,000 cfm cyclone

Capital charge = $(0.2668)(34,700)$	\$ 9,300
L&WCC = $(0.05)(9,300)$	500
Operations = $(159 \text{ mh})(20.13)$	3,200
Maintenance = $(0.04)(34,700)$	1,400
Miscellaneous	2,100
Power = $(340,000 \text{ kW-hr})(0.03)$	10,200
Total	<u>\$ 26,700</u>

Drying, Magnetic Separation, and Loading Dust

30,000 cfm wet impingement scrubber	
Capital charge = $(0.2668)(54,000)$	\$ 14,400
L&WCC = $(0.05)(14,400)$	700
Operations = $(204 \text{ mh})(20.13)$	4,100
Maintenance	2,200
Miscellaneous	3,400
Power = $(340,000 \text{ kW-hr})(0.03)$	<u>10,200</u>
Total	<u>\$ 35,000</u>

Separation and Dewatering Liquid Waste

40-acre clay lined pond w/recycle	
Capital charge = $(0.2668)(2,347,600)$	\$ 626,300
L&WCC = $(0.05)(626,300)$	31,300
Operations = $(2,250 \text{ mh})(20.13) \left(\frac{330}{240}\right)$	62,300
Maintenance = $(.03)(626,300) \left(\frac{330}{240}\right)$	25,900
Maintenance parts, supplies, miscellaneous	28,900
Power = $(663,000 \text{ kW-hr})(0.03)$	<u>19,900</u>
Total	<u>\$ 794,600</u>

Unloading and Grinding Dust

10,000 cfm cyclone	
Capital charge = $(0.2668)(8,800)$	\$ 2,400
L&WCC = $(0.05)(2,400)$	100
Operations = $(40 \text{ mh})(20.13)$	800
Maintenance	300
Miscellaneous	500
Power = $(66,700 \text{ kW-hr})(0.03)$	<u>2,000</u>
Total	<u>\$ 6,100</u>

Ignition and Drying Dust

6,000 cfm low energy venturi scrubber	
Capital charge = $(0.2668)(16,000)$	\$ 4,300
L&WCC = $(0.05)(4,300)$	200
Operations = $(75 \text{ mh})(20.13)$	1,500
Maintenance = $(0.04)(16,000)$	600
Miscellaneous	1,000
Power = $(80,000 \text{ kW-hr})(0.03)$	2,400
Total	<u>\$ 10,000</u>

Packaging Dust

1,200 cfm baghouse filter	
Capital charge = $(0.2668)(8,200)$	\$ 2,200
L&WCC = $(0.05)(2,200)$	100
Operations = $(25 \text{ mh})(20.13)$	500
Maintenance = $(0.04)(8,200)$	300
Miscellaneous	300
Power = $(17,000 \text{ kW-hr})(0.03)$	500
Bag replacement	300
Total	<u>\$ 4,200</u>

By-Product Recovery Dust

15,000 cfm wet impingement scrubber	
Capital charge = $(0.2668)(30,000)$	\$ 8,000
L&WCC = $(0.05)(8,000)$	400
Operations = $(110 \text{ mh})(20.13)$	2,200
Maintenance = $(0.04)(30,000)$	1,200
Miscellaneous	1,800
Power = $(170,000 \text{ kW-hr})(0.03)$	5,100
Total	<u>\$ 18,700</u>

Liquid Waste to Tailings Pond

6-acre pond w/clay liner, no recycle

Capital charge = $(0.2668)(209,300)$ \$ 55,800

L&WCC = $(0.05)(55,800)$ 2,800

Operations = $(70 \text{ mh})(20.13)$ 1,400

Maintenance = $(0.01)(209,300)$ 2,100

Total \$ 62,100

Tailings Pond Beach Dust

Spraying operations

Capital charge = $(0.2668)(4,000)$ \$ 1,100

L&WCC = $(0.05)(1,100)$ 100

Operations = $(50 \text{ mh})(20.13)$ 1,000

Maintenance = $(0.04)(4,000)$ 200

Miscellaneous, chemicals, etc. 200

Total \$ 2,600

Tailings Pond Cover

6 ft earth w/6 in. rock cover

Sinking fund = $(0.04925)(96,900)$ \$ 4,800

F.7 CONWAY GRANITE ANNUAL COSTS

Mine Water

4-acre settling pond and pumping system	
Capital charge = $(0.2338)(293,000)$	\$ 68,500
L&WCC = $(0.05)(68,500)$	3,400
Operations = $(418 \text{ mh})(20.13)$	8,400
Maintenance	12,600
Power = $(2,010,000 \text{ kW-hr})(0.03)$	60,300
Total	<u>\$ 153,200</u>

Uncontrolled Dust

Spraying and storage pile barriers	
Capital charge = $(0.2338)(225,000)$	\$ 52,600
L&WCC = $(0.05)(52,600)$	2,600
Operations = $(2,340 \text{ mh})(20.13)$	47,100
Maintenance = $(0.03)(225,000)$	6,800
Fuel, Chemicals, etc.	60,000
Total	<u>\$ 169,100</u>

Unloading, Crushing, and Grinding Dust

2-50,000 cfm cyclones	
Capital charge = $(0.2338)(69,500)$	\$ 16,200
L&WCC = $(0.05)(16,200)$	800
Operations = $(338 \text{ mh})(20.13)$	6,800
Maintenance	3,100
Miscellaneous	4,500
Power = $(720,000 \text{ kW-hr})(0.03)$	21,600
Total	<u>\$ 53,000</u>

Mill Drying and Packaging Dust

30,000 cfm wet impingement scrubber

Capital charge = $(0.2338)(54,000)$	\$ 12,600
L&WCC = $(0.05)(12,600)$	600
Operations = $(220 \text{ mh})(20.13)$	4,400
Maintenance	2,400
Miscellaneous	3,600
Power = $(375,000 \text{ kW-hr})(0.03)$	<u>11,300</u>
Total	<u>\$ 34,900</u>

Liquid Waste to Tailings Pond

20-acre clay lined pond w/recycle system

Capital charge = $(0.2338)(908,300)$	\$ 212,400
L&WCC = $(0.05)(212,400)$	10,600
Operations = $(2,500 \text{ mh})(20.13)$	50,300
Maintenance	70,500
Supplies	11,000
Power = $(253,000 \text{ kW-hr})(0.03)$	<u>7,600</u>
Total	<u>\$ 368,400</u>

Refinery Waste Sludge

Truck to clay lined landfill

Capital charge = $(0.2338)(178,500)$	\$ 41,700
L&WCC = $(0.05)(41,700)$	2,100
Operations = $(700 \text{ mh})(20.13)$	14,100
Maintenance	5,300
Miscellaneous and fuel	<u>2,300</u>
Total	<u>\$ 65,500</u>

Refinery Drying and Packaging Dust

12,000 cfm baghouse and HEPA filter w/conditioning

- Baghouse filter

Capital charge = $(0.2338)(57,800)$	\$ 13,500
L&WCC = $(0.05)(13,500)$	700
Operations cost	3,900
Maintenance	2,400
Miscellaneous	1,900
Power	5,500
Replacement bags	2,900
Subtotal	<u>\$ 30,800</u>

- HEPA filter

Capital charge = $(0.2338)(117,000)$	\$ 27,400
L&WCC = $(0.05)(27,400)$	1,400
Operations	2,100
Maintenance	4,900
Miscellaneous	2,600
Power	1,700
Replacement filters	11,200
Subtotal	<u>\$ 51,300</u>

- 2,000 cfm conditioner

Capital charge = $(0.2338)(12,000)$	\$ 2,800
L&WCC = $(0.05)(2,800)$	100
Operations = $(0.02)(12,000)$	200
Maintenance = $(0.03)(12,000)$	400
Miscellaneous	1,000
Power	4,000
Subtotal	<u>\$ 8,500</u>

Total Annual Cost = \$30,800
+51,300
+ 8,500 = \$90,600

Refinery Tailings Pond

10-acre clay lined evaporation pond, no recycle

Capital charge = $(0.2338)(326,800)$	\$ 76,400
L&WCC = $(0.05)(76,400)$	3,800
Operations = $(100 \text{ mh})(20.13)$	2,000
Maintenance = $(0.01)(326,800)$	3,300
Supplies and miscellaneous	<u>500</u>
Total	<u>\$ 86,000</u>

Refinery Tailings Pond Beach Dust

Spraying operation

Capital charge = $(0.2338)(4,000)$	\$ 900
L&WCC = $(0.05)(900)$	100
Operations and maintenance	<u>2,100</u>
Total	<u>\$ 3,100</u>

Refinery Tailings Pond Cover

6 ft earth w/6 in. rock cover

Sinking fund = $(0.00976)(145,800)$	<u>\$ 1,400</u>
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