Tailings Management Plan
Proposed Ore Processing Facility
Shootering Canyon
Uranium Project, Utah

Woodward-Clyde Consultants

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for

Plateau Resources Ltd
Grand Junction, Colorado

Revised May 1978

Woodward-Clyde Consultants
Three Embarcadero Center, Suite 700, San Francisco, CA 94111

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INTRODUCTION

Construction of a uranium ore processing facility near the existing Shootering Canyon* uranium mine is proposed. Further, it is proposed to impound the tailings from this facility in a natural surface depression. An embankment dam will be used to close the existing drainage outlet from this depression.

Tailings will be hydraulically transported from the uranium facility to the tailings impoundment (pond). In the pond, the solid tailings will settle from the transporting liquid and the liquid will be removed from the disposal system by evaporation to the atmosphere. Recycling of a portion of the liquid for use in the process is being evaluated. The bottom of the tailings pond will be lined with compacted clay to control seepage flows into the underlying strata in order to minimize potential degradation of groundwaters by plant effluents.

Throughout the service life of the pond the tailings will be kept wet with plant effluents, which are primarily water. This water will prevent dispersion of the fine-grained tailings by wind, aid in absorption of radiation emitted by radionuclides in the tailings, and restrict release of radon gas resulting from the decay of radium in the tailings.

At the end of the service life of the facility, or when the pond capacity is fully utilized, the tailings in the pond will be capped with compacted clay; then the clay will be covered with a layer of sandy material which will in turn be covered with a layer of gravel and cobbles. Collectively the three layers of capping materials will defer erosion and dispersion of the tailings by either wind or water; absorb

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*Also known as Shitamaring Canyon and Shootaring Canyon.

gamma radiation emitted from the tailings; and control the release into the atmosphere of radon gas emanating from the tailings.

On the basis of information provided in the report "Preliminary Site Selection Study" (Woodward-Clyde Consultants, June 1977) for the Shootering Canyon ore processing facility and tailings disposal pond, Nuclear Regulatory Commission representatives have stated that "adequate consideration was not given to possible alternative tailings management plans." (Copies of that report are being submitted to the NRC accompanying this report). In particular, the NRC staff requested consideration of below-grade disposal options. This report is intended to elaborate on potential tailings management alternatives and to indicate that the proposed tailings management plan results, in essence, in below-grade disposal, in that the area to be used for the tailings impoundment is clearly below the general grade of the surrounding landforms.

DISPOSAL ALTERNATIVES

Four tailings disposal alternatives were evaluated, as follows:

1. Disposal in a natural basin closed by an impoundment dam (the proposed plan)
2. Below-ground disposal in an excavated pit located on a mesa
3. Disposal in an excavated pit within an aboveground containment dike, located on a mesa
4. Disposal by burial in worked-out parts of the mine

Methods 1, 2, and 3 must be designed and operated to control seepage of tailings liquids into and through the underlying soils to the groundwater, and all will have comparable requirements for sealing the surface at project termination to limit radon emissions to the atmosphere. Also, the method of delivering and discharging tailings would be essentially the same for the three types of containment structure. For this evaluation it was assumed that the three types of tailings containments would be constructed at equivalent distances from the ore processing facility and that the only significant differences in those three disposal options, with respect to controlling seepage and radon emissions, would be due to the differences in bottom and top surface areas of the containments. Delivery and discharge of tailings to the containments was considered to be of equivalent cost and consequences for the three disposal methods.

The project mine would be about 4 miles from the ore processing plant. Transport of tailings from the plant to the mine would require a significantly longer pipeline and a greater pumping effort than if the tailings were delivered to impoundments adjacent to the plant as contemplated for disposal alternatives 1, 2 and 3.

PROPERTIES OF TAILINGS

For purposes of this report the important physical, chemical, and radiological properties of tailings from the Shootering Canyon uranium plant are assumed to be as follows:

1. Fine to medium-sized sand particles will be present in sufficient quantity to dominate the hydraulic transport and settlement characteristics of the tailings slurry. No appreciable fraction of the particles in the slurry is expected to be larger than medium-sized sand grains. Fines (material passing a number 200 sieve) are anticipated to represent about 15% of the solids content of the slurry.

2. The slurry liquid as discharged to the impoundment will have the properties of an aqueous sulfuric acid solution, with a pH of 1.5 to 2.0. Degradation of groundwater could result from seepage of tailings liquid from the impoundment.

3. Small amounts of uranium and most of the origianl quantities of daughter elements of uranium will remain in the tailings. Most important of these, with respect to the problems of tailings disposal, are radium and radon. Radium is a problem because it may be present in sufficient quantity in the tailings to cause radiological damage in living organisms when concentrated by active or inactive environmental factors. Because of its slow decay rate (half-life about 1600 years), the presence of radium is a long-term problem. Radon can also be a problem because, as a gas, it may escape into the atmosphere, adding to the radioactivity burden on living things before it decays (half-life 3.823 days). In addition, after radon decays in the atmosphere, its long-lived daughter products lead-210 (21 years) and polonium-210 (138 days) commonly attach to fine atmospheric dust and can thereby remain airborne for a considerable time. Also if the tailings are permitted to dry and are exposed to the

atmosphere erosion and dispersion of the tailings with attached radionuclides may become a factor of major concern.

It is anticipated that satisfactory solutions to the problems of minimizing seepage from the tailings pond, preventing wind and water dispersion (erosion) of the tailings particles, preventing significant diffusion of radon gas to the atmosphere, and absorbing practically all radiation emitted by the tailings within the tailings disposal system will concurrently result in a satisfactory solution to other, lesser problems incident to the long-term disposal of tailings from the Shootering Canyon ore processing facility.

QUANTITY OF TAILINGS

The preliminary design of the tailings disposal system for the Shootering Canyon uranium ore processing facility was based on 20 years of plant operations at an average ore processing rate of 750 tons per day of dry ore. Accordingly, the cumulative quantity of tailings, over the design life of the tailings disposal system, would be approximately 5.5 million tons (dry basis).

For the purposes of this analysis it was assumed that, for all disposal methods considered, the tailings would be discharged from the processing facility as a slurry containing 45% solids (by weight) and that in the tailings disposal facility the tailings would be dewatered by evaporation and drainage to the extent that the in-place tailings would have an average saturated density of about 122 pounds per cubic foot, or a dry density of about 97 pounds per cubic foot. The moisture content of the settled tailings would average about 26% (weight of water/weight of solids). In accordance with these assumptions, the total volume of settled tailings over 20 years would be about 2600 acre-feet, and this is the capacity of the tailings disposal facility considered in this study. It should be noted that presently identified ore reserves in the Shootering Canyon vicinity are assumed sufficient for 15 years of plant operations, and this is the design life adopted for all project facilities except the tailings disposal facility. It was considered appropriate to plan for accommodating the additional quantity of tailings in case more economically recoverable ore is located by the on-going exploration program.

The quantity of liquid in the tailings slurry, as discharged from the process circuit, would be about 230 to 250 acre-feet per year. Settled tailings, as assumed for this analysis, would retain between 50 and 90 acre-feet per year of the slurry liquid, and 160 to 200

acre-feet per year of liquid would be removed from the slurry by evaporation and drainage. Drainage may include liquid decanted from the settled tailings as well as seepage losses from the containment. Decanted liquids may be either returned to the process circuit or recirculated within the containment to increase evaporative losses and for wetting exposed tailings.

OBJECTIVES OF A TAILINGS MANAGEMENT PLAN

The primary objectives in designing a plan for managing tailings from a uranium plant include the following:

- The disposal system must function reliably under all conditions of facility operation.
- The system must operate safely, with regard to both radiological hazards and direct physical injury, and under all conditions of facility operation.
- The system must be economically viable.
- Losses of liquid from the tailings disposal area must be limited to the extent that they will not degrade surface waters or groundwaters or present an unacceptable burden on the water supply for the area.
- Gamma ray emissions and radon gas emanating from the tailings must be controlled to acceptable limits.
- The tailings must be confined so that the contained radium and other radionuclides are not distributed by wind or water erosion over the long term.

NATURAL BASIN WITH IMPOUNDMENT DAM

In the general vicinity of Shootering Canyon there are several isolated canyons or drainage depressions that have become separated from their original larger catchment areas by capture of much of the drainage areas by other streams. The result is naturally excavated basins, commonly several hundred acres in extent, separated from the presently active drainage courses by massive walls of rock. In some instances the rock walls or cliffs swing around almost full circle to practically enclose the basins. These basins have attributes well suited to the disposal and storage of uranium tailings, after closure with impoundment dams. Also, reclamation of the basins at project termination would be relatively easy. Naturally higher land adjacent to some of these basins provides excellent plant sites. In 1977 Woodward-Clyde Consultants made a thorough investigation of the Shootering Canyon vicinity and analyzed all the natural basins in the area for their potential as tailings disposal sites. The presently proposed plant site and tailings disposal basin represents the culmination of that site selection process.* The location of the designated site is indicated in Figure 1.

A preliminary design for a tailings impoundment dam at the proposed site has been completed. Numerous borings were made and test pits dug at the dam site and in the impoundment area. Laboratory tests were performed on materials from the borings and test pits and on soils taken from nearby areas that were considered suitable for use in

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*"Preliminary Site Selection Study, Proposed Shootering Canyon Uranium Project, Utah." Woodward-Clyde Consultants, June 1977, submitted to the USNRC in docket 40-7869, License SUA 1013 on October 27, 1977; and resubmitted with this report.

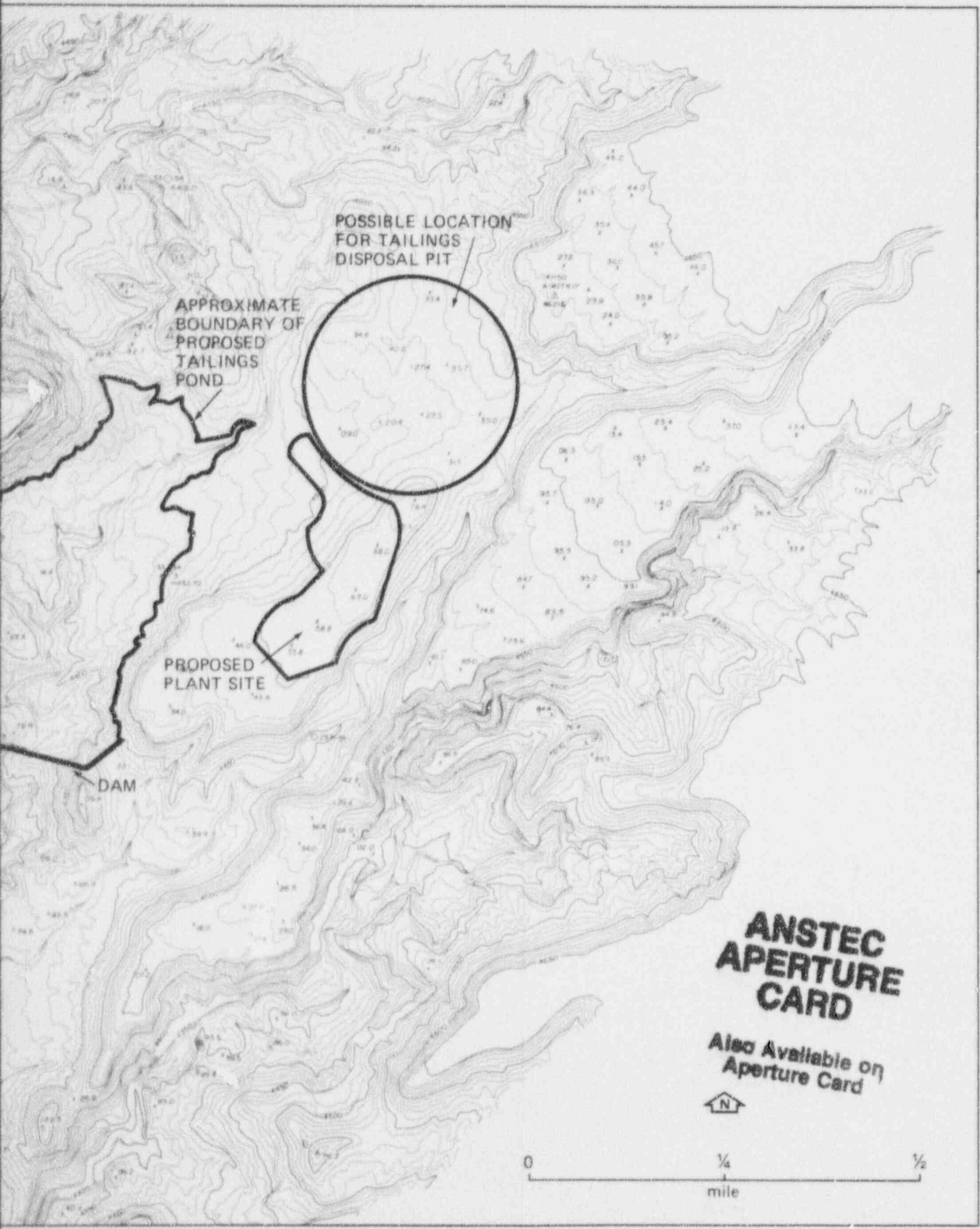

Figure 1. Shootering Canyon uranium project tailings disposal study: Locations of impoundment pond and pit disposal alternatives

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the dam, and for the clay liner to be placed over the tailings disposal area. The results of the exploration and testing program confirmed that an impoundment dam would be feasible at the proposed site. The results were presented in a separate report submitted to the USNRC with the Application for a Source Material License.* Quantities of materials required for the dam and pond liner were presented in the preliminary geotechnical report.

A project water well and four observation wells were drilled about 1000 feet east of the proposed dam site. The strata through which those wells were drilled are continuous beneath the proposed tailings disposal area. A pump test on the water well showed that the Entrada Sandstone, which would be the formation in contact with the bottom of the impoundment, has a low coefficient of permeability ($C = 2.6 \times 10^{-5}$ cm/sec). Also, the well drilling and testing programs showed that the water table under the proposed impoundment area probably is at least 100 feet below the lowest point on the bottom of the impoundment. The details and results of the well drilling and testing program are presented in Appendix C2 of the Environmental Report.

The project water supply will be drawn from the Navajo Sandstone, which is separated from the Entrada Sandstone by the Carmel Formation. The Carmel Formation is approximately 160 feet thick in the project vicinity, and because it contains many strata of clay and shale it is relatively impervious. It is not considered to be an aquifer. Results of the well pumping test indicated that there is no hydraulic connection

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*Preliminary Geotechnical Engineering Report, Shootering Canyon Uranium Project, Garfield County, Utah, Woodward-Clyde Consultants, April, 1978.

between the Navajo and Entrada aquifers. The Navajo Sandstone is approximately 800 feet thick, and it has a coefficient of permeability of about $C = 1 \times 10^{-3}$ cm/sec in the project vicinity.

Features of the proposed tailings impoundment basin which relate to the proposed use include the following:

- The basin has adequate area and capacity for storing project tailings, including the potential for storing more than the quantity of tailings assumed for preliminary planning purposes, in case more ore is processed at the proposed plant than is included in the present plans.

- Tailings would be stored well below the natural level of the surrounding area, except at the 1500-foot-long segment where closure would be made by the dam.

- A relatively smooth and gently sloping bottom would facilitate placement of a compacted clay liner over the area.

- The basin is formed in a massive rock member with limited jointing, and the joints are sealed with gypsum and calcite.

- A small catchment area drains to the basin (220 acres). All runoff from the catchment area would be retained within the tailings basin throughout the operating life of the facility.

- The basin is about a mile upstream from the drainage junction with Shootering Creek, and backwater from floods in Shootering Creek would not affect a dam at the site.

- A satisfactory plant site is available about 500 feet northeast of the impoundment area and about 50 feet above the full impoundment level.

- Local materials suitable for use in the dam and pond liner are available in adequate quantities.

- The permeability of the underlying rock formation is low.

- The site is more than 1.5 mile from the nearest public highway (Utah State Highway 276) (276) and 14 miles from the nearest permanently occupied human habitation (Bullfrog Basin Marina). The proposed new town of Ticaboo would be more than 2 miles from the nearest part of the impoundment area.

- Geological formations beneath the impoundment area are massive, fine-grained sandstones. Vertical permeability through the stratified sandstone should be even less than horizontal permeability under the area. Therefore at least part of the seepage from the basin, if seepage occurs in significant quantity, should appear at the ground surface downstream from the dam, where it would be observed during project monitoring, and it could be collected and returned to the impoundment or process circuit.

- The basin would present sufficient surface area to permit removing all surplus liquid from the tailings by evaporation.

- After project termination there is a low probability that any runoff from precipitation in the basin would ever have to be passed downstream from the dam. Normal precipitation in the area is 6 to 8 inches per year. An excavated diversion

channel would be provided around the dam, but the inlet to the channel would be about 3 feet higher than the top of the earth and rock cover to be placed over the tailings. The dead storage space between the top of the tailings cover and the channel inlet would be adequate to contain all runoff from the maximum probable precipitation at the site, and only a closely spaced series of extreme storms could cause flow in the channel. Under normal conditions all runoff would be captured over the impoundment area and would be utilized for maintaining a relatively high moisture content in the tailings and in the clay cap over the tailings. This would facilitate control of radon emanating from the tailings.

- During project operations the pond surface area may be controlled as a variable to optimize tailings disposal. A substantial area at the upper elevations of the basin has a very gentle bottom slope, and it would be easy to construct a low dike across those areas (as indicated in Figure 2) to confine the tailings, as appropriate, for keeping the tailings surface wet and thereby preventing their dispersion by wind. If a dike of the type indicated in the figure were constructed along a contour about 20 feet lower than the full basin level, the basin surface area would be reduced from about 70 acres to 55 acres (about 20%) and the basin capacity would be reduced from about 2600 acre-feet to about 2400 acre-feet (about an 8% reduction). By increasing the height of the impoundment dam about 4 feet, the originally planned tailings capacity would be maintained; while the area requiring bottom lining and tailings capping would be reduced by 20%. Also, the source area for gamma ray emissions and radon emanation would be similarly reduced, and therefore the total emissions from the tailings would be reduced by comparable amounts.

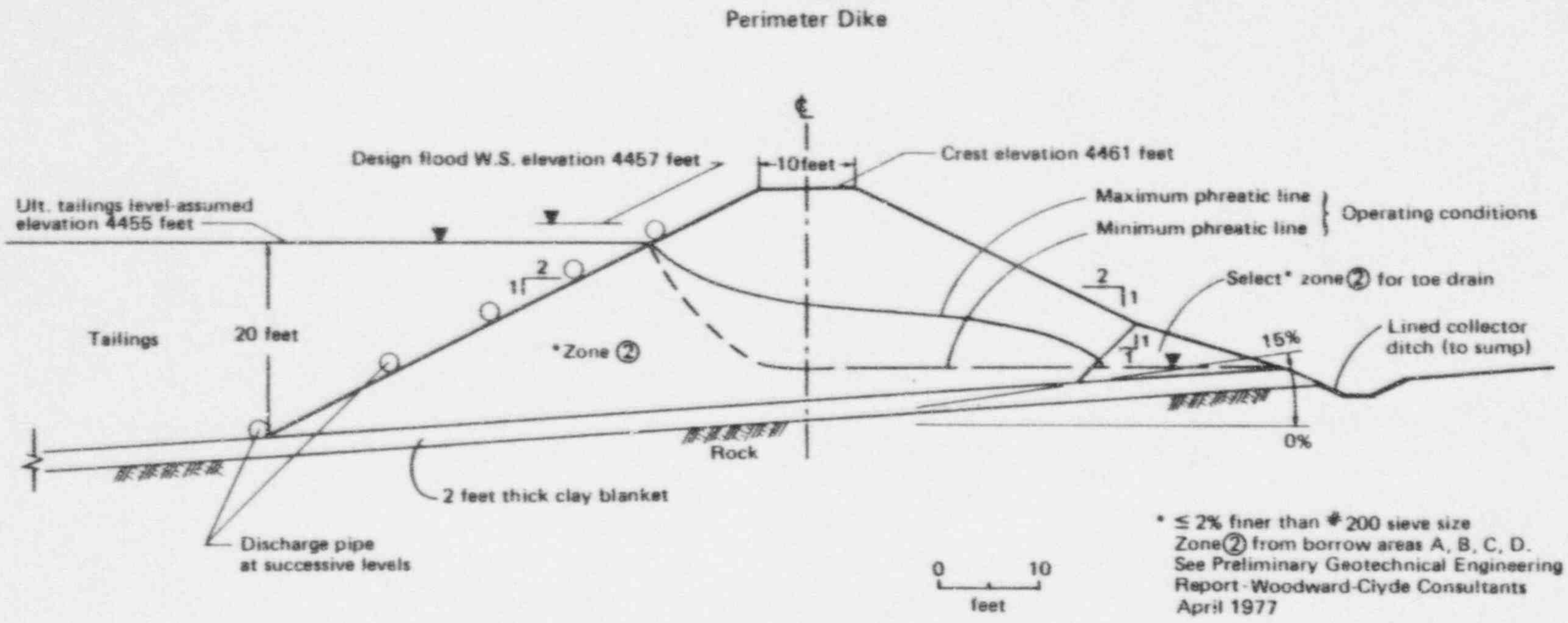


Figure 2. Shootering Canyon uranium project tailings disposal study: Tailings containment dike on nearly flat slope at pond perimeter

The proposed tailings impoundment would relate to the NRC staff's performance objectives as follows:

Siting and Design

1. Remote from people. The impoundment area would be 14 miles from the nearest existing permanently occupied area (Bullfrog Basin Marina). Few people now live within 50 miles of the project site, and the nearest existing community is 60 miles north of the site. That community is Hanksville, and it has a population of less than 200 persons. The proposed new town of Ticaboo would be more than 1.5 miles from the impoundment area. Population exposures from the proposed facility would be limited to the maximum extent reasonably achievable.

2. Dispersion by natural forces. The proposed impoundment would be sited in a natural, geologically stable basin. Throughout the operating life of the facility, the impoundment dam would be maintained sufficiently higher than the tailings level in the basin so that the basin could always contain the full volume of runoff resulting from the maximum probable precipitation at the site. Therefore there would be no risk of tailings dispersion by runoff waters during the operating life of the facility. After reclamation of the impoundment area a diversion channel would be available to pass extreme accumulations of runoff around the dam, without that runoff affecting the dam or the tailings behind the dam. Tailings dispersion by runoff would be precluded by the proposed operating and reclamation procedures.

The dam would be designed to be stable throughout the maximum probable seismic event likely to occur at the site. Water would be continuously removed from the tailings by evaporation during the operating life of the facility in order to consolidate the slimes fraction to the maximum feasible extent. Dewatering of the tailings during placement

would result in a relatively dense and stable mass. Accordingly, even a complete rupture of the dam (which is not considered a credible event) would not cause a significant amount of tailings dispersion.

During operation the tailings surface would be kept wet by tailings liquid. Keeping the tailings wet would prevent their dispersion by wind. At the end of the operating life of the impoundment the tailings would be capped, and the top layer of the cap would be cobbles, gravel, and sand. This layer would be extremely resistant to dispersion or movement by wind, and it would prevent wind from having access to lower layers of the cap. Also, sediments transported onto the impoundment area by runoff would be retained on the cap, so the cap thickness should increase over time. Further, the naturally depressed surface of the impoundment area, particularly with respect to the high bluff west of the area, should cause the area to be a depository for wind-borne sands rather than a source of material for wind erosion, and this too should add to the thickness of the cap.

Exposed surfaces of the dam would be covered with gravel and cobbles, and those surfaces would be stable against erosion by either wind or water. The performance objective of eliminating or reducing tailings dispersion by natural forces to the extent reasonably achievable would be satisfied by the proposed tailings impoundment.

3. Seepage of toxic materials into the groundwater. The proposed tailings impoundment would be lined with compacted clay to limit the seepage of tailings liquids from its bottom. The pond would be operated so as to remove as much liquid as feasible from the tailings by evaporation, in order to minimize the amount of liquid available for seepage from the basin. Slimes contained in the tailings would act to plug the pore spaces in the clay liner. Also, if any slimes passed through the liner they would plug the pore spaces in the fine-grained sandstone

underlying the area. Therefore, the impoundment would tend to be self-sealing.

There are relatively high concentrations of calcite in the sandstone under the impoundment. Calcite would react with sulfuric acid in the tailings liquid and tend to neutralize it. As the pH of the liquid was increased, the solubility of several types of toxic ions in the liquid would be decreased; and those ions would be precipitated from the liquid before the liquid reached the groundwater. The precipitated ions would attach themselves to the sandstone particles at the points of precipitation. The minimum of 100 feet between the basin bottom and the groundwater should provide sufficient calcite to neutralize the amount of liquid that would seep from the impoundment.

The horizontal permeability of the stratified sandstone underlying the basin should be greater than its vertical permeability. This should cause some horizontal component of flow to seepage liquids. It is expected that if a significant amount of liquid escaped the impoundment by seepage, then some of that liquid would flow horizontally and it probably would appear at the ground surface downstream from the dam. Observation wells would be provided below the dam. If water was observed in the wells it would be sampled and tested to determine its properties and probable source. If appropriate, collector wells would then be installed at carefully selected points to maximize the capture of seepage liquid and to prevent its movement toward the groundwater surface.

The proposed tailings impoundment would be designed such that the seepage of tailings liquid to the groundwater would be reduced to the maximum extent reasonably achievable.

During Operations

4. Eliminate blowing tailings. The method to be used for placing tailings in the proposed impoundment would be effective in preventing tailings dispersion by wind during the entire project operating life. Throughout the operation, exposed tailings surfaces would be kept wet with tailings liquid as a result of the manner in which the tailings would be discharged to the impoundment. The impoundment area would be sheltered from extreme winds by the higher ground surrounding the area, particularly the high bluff along the entire west side of the area. It is expected that there would be a net deposition of wind-borne material over the impoundment area throughout its operating life, and also after project termination and impoundment closure. Blowing of tailings to unrestricted areas would be controlled to the maximum extent reasonably achievable throughout the operating life of the facility.

Post-Reclamation

5. Reduce direct gamma radiation. The layered cap of earth materials required to be placed over the tailings at closure of the impoundment facility, for the purpose of controlling radon emanation, would be of such great thickness and mass that it would absorb practically all gamma radiation originating from the tailings before the rays could penetrate to the environment. The cap would be of sufficient mass to reduce gamma radiation to an intensity essentially equal to the natural background radiation in the area.

6. Reduce radon emanation. Radon emanation from the tailings cap would be limited to approximately twice the emanation rate from the surrounding environs by the manner in which the cap is designed, constructed, and operated in the post-reclamation period. A subsequent

section of this report presents the basis for the cap design and construction. (The design of the cap would be the same for other tailings impoundment alternatives included in this analysis and is thus discussed only once.) The special merit of the tailings cap for the proposed impoundment is the way in which it would operate. The proposed impoundment would maximize the opportunity to capture incident precipitation, and runoff from the adjacent catchment, in order to keep the moisture content of the clay cap and the tailings as high as possible. Moisture contained in soil is effective in reducing the radon dispersion coefficient for the soil. Also, runoff captured on the impoundment area would deposit sediments thereon, and the dissolved minerals in the runoff would form a caliche layer in the soil as the water was subsequently evaporated. Over time, the sediments and caliche would accumulate to the extent that they too would contribute to the retention of radon within the cap. In particular, the surface layer of cobbles, gravel, and sand on the cap would have a small capacity for retaining water, and practically all rainfall on the cap and runoff from the basin catchment area would pass through the layer into the underlying layer of sandy material. However, the surface layer would serve to limit evaporation from lower-lying layers, because it would serve as an insulating layer and there would be little circulation of air through the layer.

The NRC performance objective for limiting radon emanations would be satisfied by the proposed tailings impoundment system.

7. <u>Eliminate need for ongoing monitoring</u>. All aspects of the proposed tailings impoundment system would be designed and constructed so that there should be no need for monitoring or maintenance of the system after project termination. However, it must be recognized that for any system some minimal amount of monitoring would be required to establish that the system was performing as intended and that no maintenance was required. The Environmental Report contains a description of the

monitoring system proposed for the Shootering project. The monitoring system would require occasional visual inspection of the dam, diversion channel, and impoundment surface for about 5 years after project termination, and also checking for water at the observation wells downstream from the dam. For about a year after project termination, radon emanation and gamma radiation would be measured at prescribed locations on the impoundment cap, and at nearby locations to establish background rates. After the initial monitoring had established that the system was performing as designed, there should be little or no further need for additional monitoring, nor any need for maintenance of the tailings disposal system.

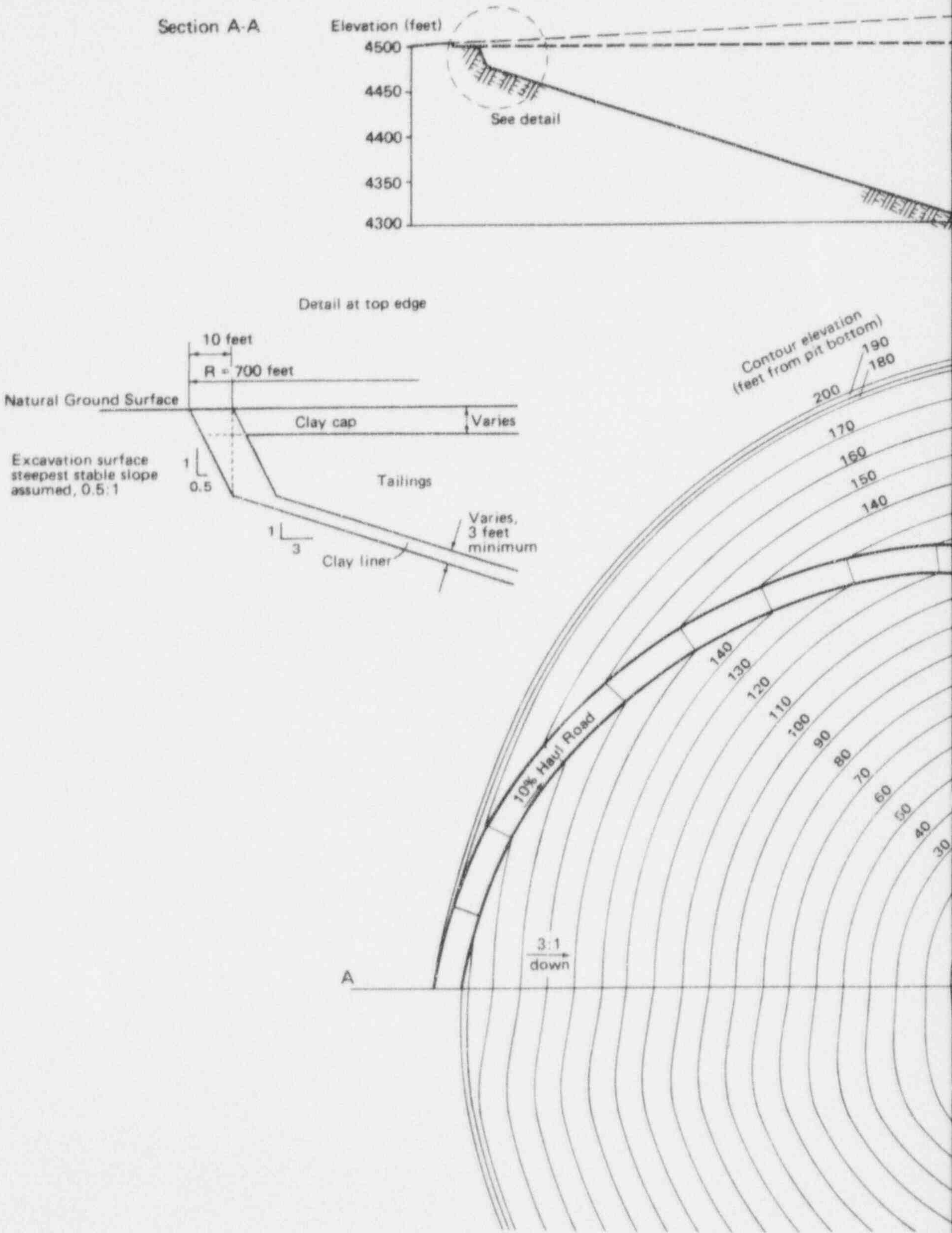
8. Financial surety arrangements. The Oil, Gas, and Mining Division of the Utah State Department of Natural Resources requires that operators of mines and ore processing plants in the state obtain a bond to ensure that decommissioning obligations are satisfactorily performed and completed. The amount of this bond will be determined after that agency has reviewed the permit application, reclamation plan, and estimated cost of the reclamation work. Plateau Resources Limited is prepared to execute the necessary bond at the appropriate time.

It is concluded that the State of Utah's bonding requirements would assure that a satisfactory reclamation program of the tailings disposal area would be completed if the project tailings were placed in the proposed impoundment. Accordingly, the NRC performance objective would be satisfied with this disposal alternative.

EXCAVATED PIT

Tailings disposal in a pit excavated for the purpose was included in the evaluation of disposal alternatives. A major objective of this disposal technique would be to place the entire volume of project tailings below the natural ground surface in a geologically stable area. The governing assumption related to the method is that the upper surface of the in-place tailings would not be subject to wind erosion over the time-frame that the disposal system must serve.

In the vicinity of the Shootering Canyon project the number of adequately large, nearly level, and accessible areas that would satisfy the criteria of surface stability is limited. An area that probably would be satisfactory is located immediately to the north of the proposed plant site, as indicated in Figure 1. Economic utilization of this site would require an approximately circular disposal pit which could not be more than about 1400 feet in diameter. Assuming that a pit side slope of approximately 3 to 1 (3 horizontal to 1 vertical) is the steepest that may be practically developed at this location, then the pit would have to be approximately 200 feet deep to accommodate 2600 acre feet of tailings, after making due allowance for lining the pit with clay to limit seepage. A preliminary plan and cross section of a disposal pit, as used for this analysis, is presented in Figure 3. Quantity estimates for excavation, lining, and capping the indicated facility are as follows:


Section A-A
Elevation (feet)
4500
4450
4400
4350
4300
See detail
Detail at top edge
10 feet
R = 700 feet
Natural Ground Surface
Clay cap
Varies
Excavation surface steepest stable slope assumed, 0.5:1
1
0.5
Tailings
1
3
Varies, 3 feet minimum
Clay liner
Contour elevation (feet from pit bottom)
200
190
180
170
160
150
140
140
130
120
110
100
90
80
70
60
50
40
30
10% Haul Road
3:1 down
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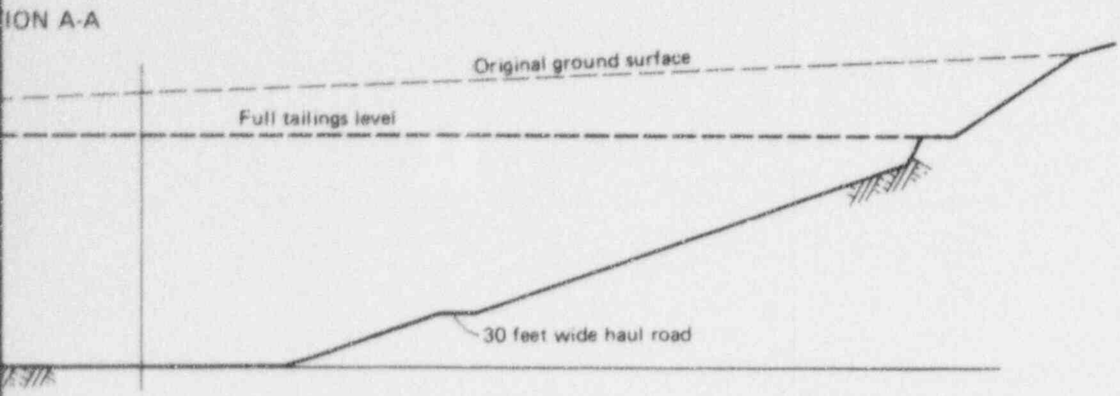

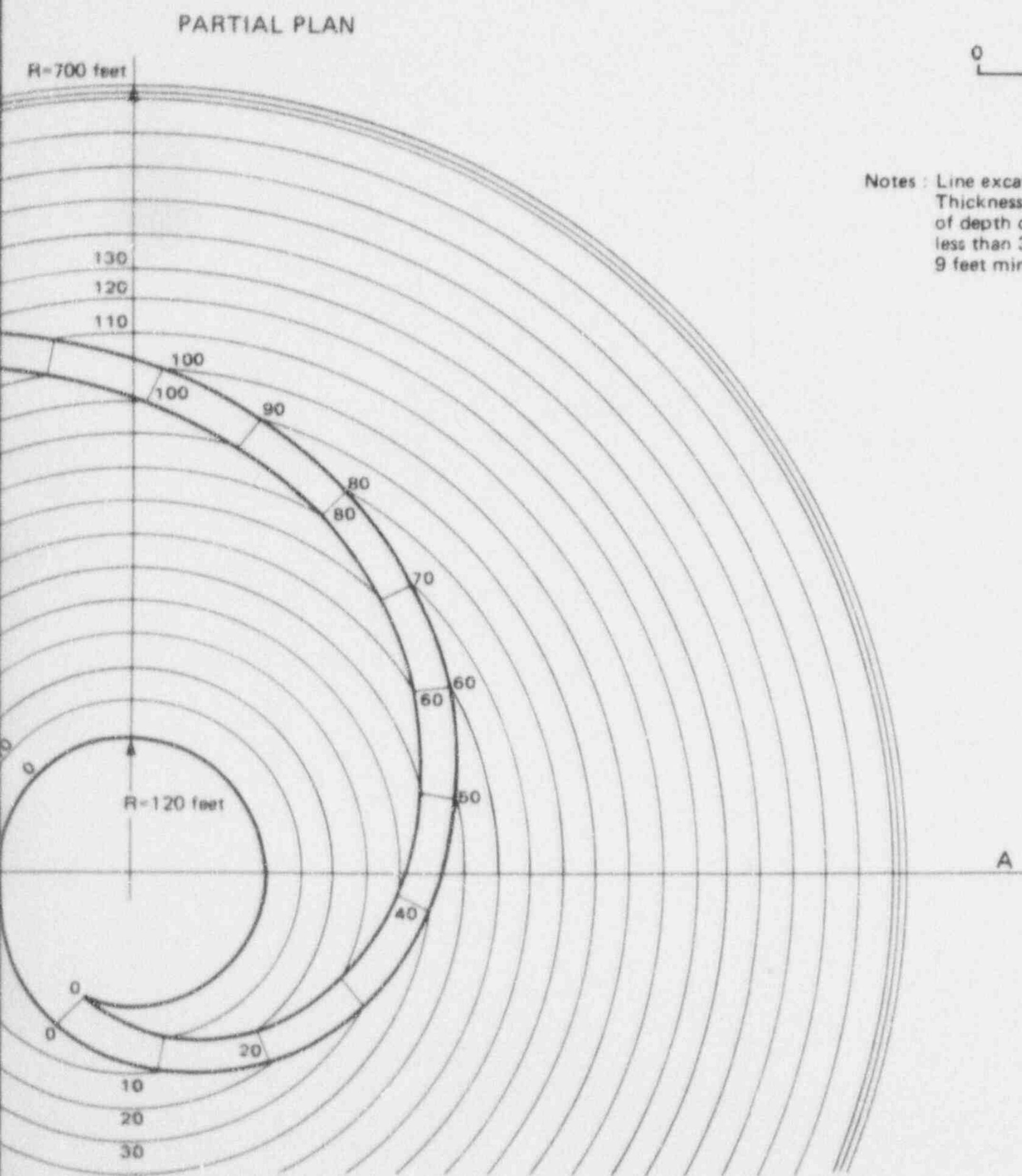

Notes : Line excavation with compacted clay; Thickness of lining to be 10 percent of depth of overlying tailings but not less than 3 feet (horizontal width 9 feet minimum).

Figure 3. Shootering Canyon uranium project tailings disposal study: Disposal in excavated pit--pit excavation plan, section, detail

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	Estimated Quantities	
	Cubic Yards	Acre-Feet
Overburden removal (above elev. 4500 ft)	2,000,000	1240
Pit excavation (below elev. 4500 ft)	5,330,000	3300
Total excavation	7,330,000	4540
Clay lining (thickness = 10% of head)	1,000,000	620
Protective covering over lining (18 inches)	85,000	50
Clay Cap (6 ft)	300,000	190
Earth, sand and gravel cover on cap (2 ft)	120,000	70
Cobbles, gravel, and sand armor (1 ft)	60,000	35
Tailings	4,200,000	2600

The pit, as indicated in the figures, would have a full tailings level of about elevation 4500 feet, which is about 40 feet below the tailings discharge level of the plant as presently designed (preliminary design). Accordingly, gravity flow could be utilized to assist in delivering tailings to the pit throughout its operating life. It seems likely that if an excavated pit were to be used for tailings disposal the ore processing plant would be rearranged from the present plans, but the same plant site could be used with no significant complications. As a minimum, the access to the plant from both highway 276 and from the ore haul road from the mines would require reorientation. For this analysis it was assumed that plant construction and operating costs would be the same whether the presently proposed tailings disposal plan or a pit disposal plan were implemented.

None of the material excavated to construct the pit would be used in the plant construction or the tailings disposal facility, except that some material might be reclaimed and utilized in the protective

cover to be placed over the clay cap that would seal the tailings at project termination. All excess excavation could be placed in the natural basin southwest of the pit, which is presently planned to be used for tailings disposal. Such disposal of excavated material would have essentially the same visual and ecological impacts on the basin as using it for tailings disposal.

The elevation of groundwater at the indicated pit location is not known. Project water well WW-1 (Figure C2-1, Environmental Report) is located about a quarter-mile south of the center of the indicated pit location. In the spring of 1978 the water surface in WW-1 was at elevation 4270 ft (Environmental Report, Appendix C2). It then had a moderate slope from north to south at that location, and that slope probably is representative of natural conditions in the aquifer. Accordingly, it seems likely that the groundwater elevation at the indicated pit location would be near or above the elevation of the indicated pit bottom (elevation 4300 feet). A pit 200 feet deep at the indicated location would not completely penetrate the Entrada Sandstone, which probably has a lower boundary between 4000 and 4100 feet elevation in this vicinity. The Entrada aquifer has a low coefficient of transmissivity (T = 130 gallons per day per foot, Appendix C2, Environmental Report) and it should be relatively easy to dewater an excavation penetrating a nominal distance below the water table in this formation, and to place a clay liner in the excavation. Dewatering would have to be continued until the tailings in the pit extended above the level of the groundwater table in order to prevent the pit lining from being ruptured by hydraulic pressure from the groundwater.

The surface area of a pit 1400 feet in diameter is about 35 acres. Net evaporation from a free water surface in the Shootering Canyon area is approximately 3.3 feet per year. Based on this evaporation rate, approximately 50 to 60 acres of water surface would be required to

evaporate all the water to be removed from the tailings (160 to 200 acre-feet per year). It is concluded that it would not be possible to dispose of all excess tailings liquids by evaporation from the pit surface utilizing a pit of the indicated dimensions. Recycling of some tailings liquid to the plant process circuit could assist in dewatering the tailings while limiting the amount available for seepage into the groundwater. However, because complete prevention of seepage from the pit would not be possible, and because groundwater in the area is near or above the bottom of the indicated pit, there is a significant potential that water in the Entrada Sandstone in this vicinity would be degraded with this tailings disposal method.

Tailings disposal in a pit excavated as discussed above would relate to the NRC staff's performance objectives as follows:

Siting and Design

1. Remote from people. Tailings disposal in an excavated pit adjacent to the proposed Shootering Canyon plant site would satisfy the objective of being remote from people, and population exposures would be reduced to the maximum extent reasonably achievable. Plant operating staff would be the persons nearest the disposal area, and their proximity would be limited to their working hours and to the operating life of the plant. There are at present no permanent residents living within several miles of the disposal site, and no residential development other than the new town of Ticaboo, about 2 miles south of the indicated pit location, is expected in the vicinity.

2. Dispersion by natural forces. The performance objective of reducing the risk of tailings disruption or dispersal by natural forces to the maximum extent reasonably achievable would be satisfied by tailings

disposal in an excavated pit of the indicated design and at the indicated location. The part of the mesa in which the pit would be located is not subject to storm water overflow. The nearest significant drainage channel is Lost Spring Wash, which is about one-half mile north of the pit location. The mesa is clearly resistant to wind erosion, and a tailings disposal pit excavated within it and refilled to near the natural surface level should not significantly alter its resistance to erosion. Much of the area covered by the indicated pit is now covered with windblown sand, indicating the area is presently a depositional area rather than an erosional area. There are no active faults in the vicinity of the site.

3. Seepage of toxic materials into the groundwater. A pit excavated at the indicated location and to the indicated dimensions would penetrate below the natural groundwater table in the area. Since space is not available at this location to excavate a pit of greater surface area, it is necessary to go as deep as indicated in order to obtain the necessary tailings disposal capacity. Because only the pit liner would separate the tailings from the groundwater in the area, and some seepage through the liner must be expected, it is expected that some tailings liquids would enter the groundwater with the indicated pit disposal system. Therefore the performance objective of preventing groundwater degradation probably would not be satisfied with a pit tailings disposal system.

During Operations

4. Eliminate blowing tailings. Tailings disposal in a pit excavated adjacent to the proposed plant site would satisfy the performance objective of preventing tailings from being distributed by wind to unrestricted areas during the plant's operational phase. The surface of the tailings in the pit would continuously be significantly lower in elevation than the surface of the mesa in which the pit would be located. Also, the surface

of the tailings would be kept wet so the tailings would have a natural resistance to being picked up by wind.

Post-Reclamation

5. Reduce direct gamma radiation. The massive cap required to be placed over the tailings at project termination to control radon emanation from the tailings would be effective in reducing gamma radiation from the tailings disposal area to essentially background levels. Accordingly, this performance objective would be satisfied by tailings disposal in an excavated pit.

6. Reduce radon emanation. A clay and earth cap would be placed over the tailings at project termination to control radon emanating from the tailings. A later section of this report discusses the requirements and design of this cap. The cap could be designed and constructed to control radon emanation to a level of about twice the emanation rate of the surrounding area, and therefore this performance objective would be satisfied by tailings disposal in an excavated pit. It is noted that radon flux is generally expressed as intensity per unit area rather than integrated over the total area of emanation. However, the pit disposal system as considered here would present a relatively small tailings surface area as the emanating source. Therefore the total radon emanation from the pit disposal system would be correspondingly small.

7. Need for ongoing monitoring. After pit closure the needs for continued monitoring of the tailings disposal system would be minimal with a pit located and constructed as indicated in Figures 1 and 3. The pit location was selected because of its proven resistance to wind erosion and because of its small exposure to surface runoff from precipitation. Accordingly, the protective cap to be placed over the tailings at pit closure would

be exposed to little erosive action. It seems more probable that there would be a net and substantial deposition of windblown sand over the disposal area, over the years, because the surface of the disposal area at closure would be lower in elevation than the original ground surface at the pit location, and most of that surface is presently covered with windblown sand.

Groundwater degradation could occur in the vicinity of the disposal pit during the active phase of its life. However, at pit closure practically all liquid that could be removed from the tailings by drainage or evaporation would have been removed, and there would be little liquid available in the tailings that could move to the groundwater. Since no significant amount of water would enter the tailings from direct precipitation or runoff, and groundwater flow through the tailings would be negligible due to its isolation by the clay lining of the disposal pit, no water would be available to move from the tailings to the groundwater. With no liquid transfer from the tailings to the groundwater, little further degradation of the groundwater could occur and there would be no requirement to continuously monitor the groundwater in the vicinity of the disposal area after pit closure.

It is concluded that tailings disposal in an excavated pit would satisfy the NRC performance objective with respect to post-closure monitoring needs.

8. Financial surety arrangements. The Oil, Gas, and Mining Division of the Utah State Department of Natural Resources requires that operators of mines and ore processing plants in the state obtain a bond to ensure that decommissioning obligations are satisfactorily performed and completed. The amount of this bond will be determined after that agency has reviewed the permit application, reclamation plan, and estimated cost

of the reclamation work. Plateau Resources Limited is prepared to execute the necessary bond at the appropriate time.

It is concluded that the State of Utah's bonding requirements would assure that a satisfactory reclamation program of the tailings disposal area would be completed if the project tailings were placed in an excavated pit. Accordingly, this NRC performance objective would be satisfied with this disposal alternative.

COMBINATION EXCAVATED PIT AND CONTAINMENT DIKE

A tailings containment facility that would be a combination of an excavated pit disposal facility and a containment dike constructed above ground utilizing material removed from the pit was analyzed because of its obviously lower construction costs compared with those of a fully excavated pit. The facility location selected for analysis would be the same as for the excavated pit, as shown in Figure 1. In plan view, the combined cut and fill facility would appear similar to the excavated pit facility as presented in Figure 3. A cross-sectional view of the combination facility is indicated in Figure 4. In general, the excavated pit and the combination facility would have many things in common. Only the significant differences between the two types of facility are discussed here.

There are no truly level areas in the Shootering Canyon vicinity that are large enough to accommodate an excavated pit disposal facility. Therefore, in order to develop a disposal space that would be completely below the level of the adjacent ground in this vicinity, it would be necessary to first remove and waste all the material that lies above a horizontal plane passing through the lowest point on the perimeter of the selected disposal area. At the site selected for this analysis it would be necessary to remove the equivalent of about 30 feet of material over an area of about 35 acres in order to provide the requisite level starting surface. Accordingly, for the excavated pit disposal facility it would be necessary to remove about 2 million cubic yards of material that would not contribute any utilitarian value to the project. Below the starting surface each unit of excavation would provide almost a unit of tailings disposal capacity, after allowances

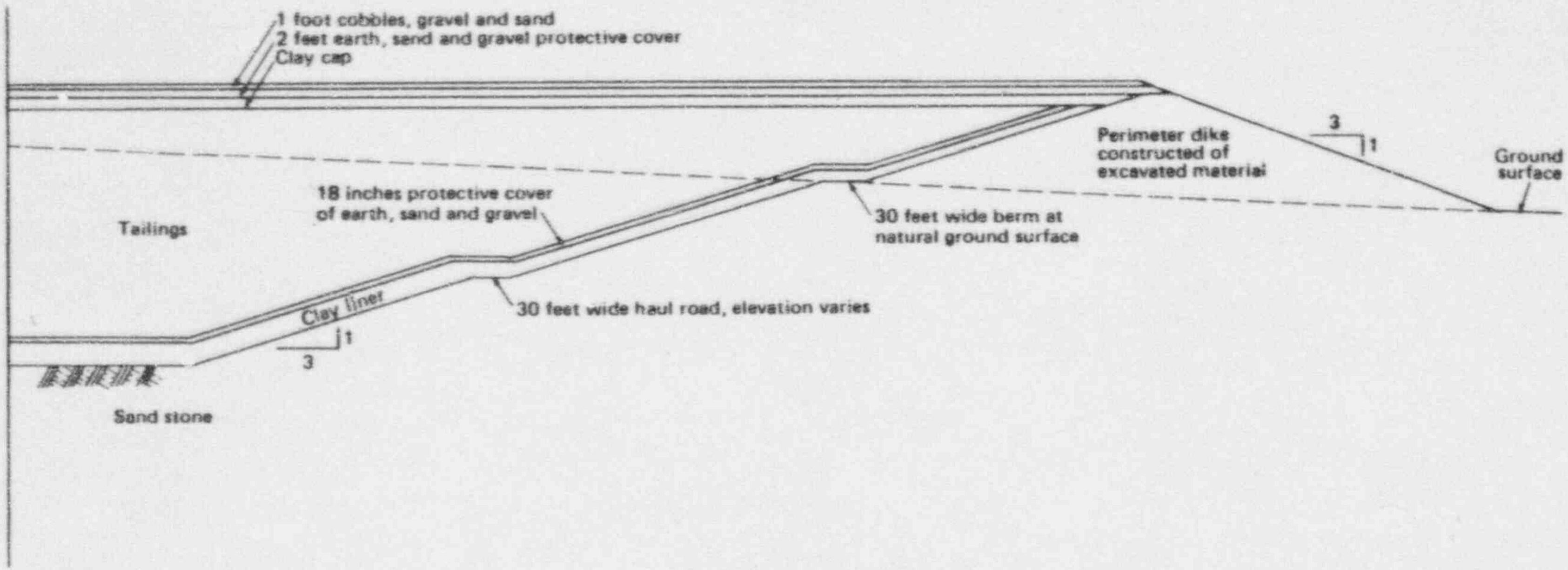

Figure 4. Shootering Canyon uranium project tailings disposal study: Tailings containment structure–combined excavated pit and dike

were made for the clay liner to be placed in the pit and for the cap to be placed over the tailings at project termination. For the selected location the total amount of excavation required would be about 7,330,000 cubic yards to provide 4,200,000 cubic yards of tailings disposal capacity -- an indicated efficiency of about 57%.

If all the material to be excavated were used to construct a dike around the perimeter of the excavation, then the total volume of excavation required in order to construct a disposal facility with a capacity to store 2600 acre-feet of tailings would be about 2.4 million cubic yards. At the site selected for analysis, the excavation would average about 140 feet deep, compared with an average depth of 230 feet for the excavated pit option. The containment dike would average about 60 feet high and it would vary in height from about 20 to 90 feet. The bottom of the excavation would be at approximately elevation 4390 feet, and the dike crest would be at elevation 4590 feet. For the excavated pit option, the pit bottom would be at elevation 4300 feet and the pit top would be at elevation 4500 feet, approximately. The two types of facilities would require approximately equal amounts of materials for lining and capping. The pit with dike option would have an indicated storage efficiency, related to volume of excavation, of 175% (4.2 million cubic yards of tailings capacity divided by 2.4 million cubic yards of excavation).

The combination pit with dike would have an advantage with respect to the simple pit in that its bottom would probably be a considerable distance above the groundwater surface in the area, whereas the simple pit would probably extend beneath the ground water surface. The potentials for groundwater degradation therefore would probably be less with the combination pit and dike.

The full tailings level of the pit and dike would be higher than the tailings discharge level from the plant. Accordingly, the tailings would have to be pumped into such a disposal facility, at least for that part of the storage above approximately elevation 4400 feet. The simple pit would require minimal pumping at any stage of the operations.

A simple pit, which would have to be entirely below the ground surface, lacks flexibility in capacity. Excavation would have to be completed before operations start, and when the tailings level approached the full pit level the facility would have to be closed. By contrast, there would be no absolute limit to the capacity of a pit and dike facility. It would be possible to add to the height of the dike at some future time if it became desirable to increase the capacity of the disposal facility. It probably would be preferable to increase the capacity of an existing containment rather than to create a second containment if additional capacity were needed.

The containment dike in a combined facility would, of course, extend above the level of the surrounding ground. Accordingly, it would be exposed to the erosive forces of wind and rain. However, because there are sufficient materials available in the Shootering Canyon vicinity that could be used for surfacing the exposed areas of the dike, and those materials have excellent erosional resistance, it would be possible to develop a dike structure that would have long-term stability against erosion.

A combination pit and containment dike tailings disposal facility would relate to the NRC staff's performance objectives as follows:

Siting and Design

1. Remote from people. The combination pit with containment dike considered would be located at the same site as the excavated pit alternative. Either facility would offer the same population exposure due to siting, and either facility would reduce the population exposure to the maximum extent reasonably achievable.

2. Dispersion by natural forces. The excavated pit with dike facility would present a substantial surface area of dike to wind and precipitation. However, those surfaces would be resistant to those forces and would protect the contained tailings from exposure to those forces. Accordingly, the performance objective would be satisfied by this disposal alternative, although conceivably to a marginally lesser degree than the excavated pit option, or than the natural basin with impoundment dam option.

3. Seepage of toxic materials into the groundwater. The excavated pit with dike facility would be approximately 90 feet higher in elevation than the excavated pit facility, and probably all of it would be above the groundwater surface; whereas the excavated pit would probably extend below the groundwater surface. Accordingly, the pit with dike facility probably would offer a lesser potential for groundwater degradation than the excavated pit facility, at least to the extent that calcite in the sandstone between the pit bottom and the groundwater would neutralize seepage liquid before it reached the groundwater, and in the process would cause precipitation and deposition of toxic ions from the liquid before the liquid entered the groundwater. Compared to the natural basin with impoundment dam alternative the volume of sandstone between the bottom of the disposal facility and the groundwater surface would be less with the combination pit with dike facility. Therefore it is assumed that the quantity of caliche available for neutralizing toxic seepage water before it entered the groundwater would be less with a combination

pit with dike facility than with a natural basin facility. However, the pit with dike facility would probably satisfy the NRC performance objective at this location.

During Operations

4. Eliminate blowing tailings. Throughout the project operations the pit with dike facility would have a perimeter dike which extended well above the level of the tailings in the containment, and this dike would deflect much of the wind's force from the surface of the tailings. The facility would present a relatively small exposed surface of tailings at all times, and less than required for removal of all excess liquids from the tailings by evaporation. Therefore the tailings surface probably would always be wet and tailings would have adequate resistance to dispersion by wind. This NRC performance objective would be satisfied in this case.

Post-Reclamation

5. Reduce direct gamma radiation. The thick and massive cap of earth materials required to be placed over the tailings at project termination to control radon emanation from the tailings would be adequate to absorb the energy of gamma radiation emerging from the tailings. The pit with dike facility would satisfy this NRC performance objective.

6. Reduce radon emanation. A clay and earth cap would be placed over the tailings at project termination to limit radon emanation to the environs. A following section of this report presents a discussion of the capping requirements, which is applicable to each of the open impoundment disposal alternatives considered. The pit with dike facility would have the same amount of exposed surface at project termination as the excavated pit alternative, and the total amount of radon emanating from the two types of facility would be approximately equal and not

more than about twice the emanation rate in the surrounding environs. The NRC performance objective would be satisfied in this instance.

7. Need for ongoing monitoring. The pit with dike facility would be designed, constructed, and operated so as not to require ongoing monitoring or maintenance after project termination. A few years of inspection-type monitoring would be required after project termination to verify that the facility was performing as intended. Visual inspection would be sufficient to determine that the dike was stable and that the tailings cap and containment dike were not being eroded by wind. Measurements would be required to establish that radon and gamma radiation entering the environment was within prescribed limits. The pit with dike facility would satisfy the NRC performance objective.

8. Financial surety arrangements. The Oil, Gas, and Mining Division of the Utah State Department of Natural Resources requires that operators of mines and ore processing plants in the state obtain a bond to ensure that decommissioning obligations are satisfactorily performed and completed. The amount of this bond will be determined after that agency has reviewed the permit application, reclamation plan, and estimated cost of the reclamation work. Plateau Resources Limited is prepared to execute the necessary bond at the appropriate time.

It is concluded that the State of Utah's bonding requirements would assure that a satisfactory reclamation program of the tailings disposal area would be completed if the project tailings were placed in a combination excavated pit with containment dike disposal facility. Accordingly, this NRC performance objective would be satisfied with this disposal alternative.

UNDERGROUND DISPOSAL

Tailings disposal in worked-out portions of the Shootering Canyon uranium mines was rejected as a feasible alternative primarily because there are no significant parts of the existing or planned mine workings that are considered worked-out. An extensive exploratory drilling program in the vicinity of the present mining area has revealed that uranium mineralization within the presently mined horizon is indeed widespread, although in much of the area explored the degree of mineralization is less than that required for a commercially successful extraction industry under present conditions. Disposal of tailings in existing or planned mine openings would prevent or restrict access to lower-grade adjacent ores or to ore bodies not yet discovered.

The surface topography in the vicinity of Shootering Canyon effectively prohibits access to much of the area for exploratory drilling. Plateau Resources Limited plans to continue its exploration program by long-hole drilling from adits driven to provide access to known ore bodies, and also to drive exploratory drifts to areas not accessible to surface drilling. This underground exploration program is planned to continue throughout much of the operating life of the mines. At this time it is not feasible to designate any drifts or adits as being of no future interest for continuing the ore exploration program or for possible ore extraction.

Plateau Resources Limited has completed over 1300 rotary drill holes in the Shootering Canyon area. These holes have been drilled within an area encompassing approximately 10 square miles, although the majority of the holes have been drilled within an area of about 3 square miles. Only about 12% of the holes drilled to date have shown no indication of uranium mineralization. Approximately 52% of all the holes have encountered "ore"-grade mineralization. For

a hole to be considered as having struck ore, it must penetrate at least 2 feet of rock containing at least 0.04% U_3O_8. Approximately 36% of the holes drilled to date have encountered uranium mineralization that is not presently of commercial grade but that may become commercially recoverable at some later date.

Transport of uranium tailings to old adits or drifts in the mines could be most easily and safely done hydraulically in pipelines. Tailings are withdrawn from the process circuit as a slurry, and it is difficult and costly to quickly dewater the slurry to the extent required for handling it by any means other than hydraulically. Discharge of the tailings slurry to a temporary impoundment and future transfer of the slurry (by either hydraulic or other means) to permanent disposal in the mines is not considered feasible. The technology is well established for pumping tailings slurry through a pipeline for disposal in a mine.

To contain tailings slurry within prescribed parts of a mine it is necessary to construct barriers (dams) across the mine openings at the prescribed limits of the disposal area. Complete filling of the mine cavities between barriers cannot be assured during the tailings placement procedure. Even if the mine cavities were completely filled initially, they would not remain full because the tailings mass would shrink due to loss of water by capillary flow into the surrounding rock. The spaces between the top of the tailings mass and the irregular crown of the mine tunnels would become collector spaces for radon gas. From there the gas could migrate to other parts of the mine, either through imperfect barriers at the limits of the disposal area or through the naturally porous, and possibly fractured or fissured sandstone in which the mine was excavated. Although the mine ventilation system may prevent significant worker exposure to the radon gas escaping from the tailings, it seems likely that the miners would be exposed to greater risk because of the increased amount of radon and possibly other

toxic gases (e.g.., H_2S, H_2Se, H_2Te), and possibly the metal cyans, in the environment. If future mining activities are to take place in the vicinity of the tailings disposal area, it is likely that greater radon concentrations would be encountered than if no tailings were placed in the old mines.

At the Shootering Canyon project no suitable site for constructing an ore processing plant was located in the immediate vicinity of the mines. Access to the mines is from the floor of Shootering Canyon. Space is not available on the canyon floor, outside the limits of possible flooding, for construction of the proposed plant. The selected plant site is located at the place nearest to the mines where a haul road leaving the canyon floor could be easily constructed. A pipeline about 4 miles long would be required between the proposed plant site and the mines if the tailings were to be returned to the mines. To construct and operate such a pipeline would be several times more costly than to construct and operate the 600-foot-long pipeline required for the proposed tailings disposal system.

Tailings disposal in the Shootering Canyon mines would relate to the NRC staff's performance objectives as follows:

Siting and Design

1. Remote from people. Tailings disposal in the mines would not satisfy this objective during the time (or times) when the mines were being worked because miners would be working in the vicinity of the disposal area. There would be a risk that radon gas, and possibly other toxic gases, could be distributed by the mine ventilation system or by natural flows to the places where the miners were working. Activity in the Shootering Canyon mines may continue for many years.

2. Dispersion by natural forces. Tailings placed in worked out portions of a mine would be secure against dispersion by wind and water erosion. The barriers to be constructed within the tunnels for containing the tailings would have to be designed and constructed so as to maintain their integrity under seismic loadings, as appropriate for the project site, in order to prevent tailings dispersion during earthquakes. Liquid removal from the tailings would be a slow process and as long as the tailings mass was saturated the tailings could liquify under shock loadings. Unless contained the liquified tailings could flow to presently active parts of the mine.

Radon gas, and possibly other toxic gases, could be dispersed by the mine ventilation system or by natural flows through the voids of the surrounding sandstone, fissures and fractures in the sandstone, imperfections in the tailings containment barriers, and imperfectly sealed exploratory and development borings in the vicinity. It should be noted that prospecting for and mining of uranium in the Shootering Canyon area has been under way since at least the 1940's. The locations of all borings, adits and drifts that have been made in the area are not known, nor is there any assurance that all earlier man-made openings in the rock in the vicinity of the mine were properly sealed.

Tailings disposal in the mine would not satisfy the USNRC performance objective of being secure against dispersion by natural forces during the operating life of the mine, which may extend for many years beyond the operating life of the Shootering Canyon one processing facility.

3. Seepage of toxic materials into the groundwater. It is expected that there would be little risk of contaminating groundwater in the Entrada or Navajo aquifers due to seepage from tailings placed in the Shootering Canyon mines as they are presently developed. At the Tony

M mine portal the water surface in the Entrada Sandstone is approximately 250 feet below the portal elevation. However, the Salt Wash member of the Morrison Formation, in which the mines are located, probably is an aquifer a few miles northwest of the existing Tony M mine portal. The mineralized horizon being developed for the Tony M mine section dips to the northwest, and the Tony M adit follows the dip of the horizon. Shootering Creek and other drainage channels in the vicinity intersect the Salt Wash member to the north and west of the Tony M mine portal, and flow in those drainage channels would serve as recharge for the Salt Wash. Mine development an additional one to two miles to the northwest of the present development probably would encounter groundwater. If tailings were returned to mines developed in or near groundwater there would be a significant potential for degrading the groundwater.

It should be noted that drainage to the surrounding sandstone would be the principal means available for removing liquid from tailings deposited in the mines. Liquid removal by evaporation would be negligible, and liquid removal by decantation probably would be so difficult to accomplish that it would be impractical. If a decant system were installed the decanted liquid would either have to be returned to the process circuit by pumping through a pipeline paralleling the slurry pipeline, or the decanted liquid would have to be discharged to a surface impoundment for disposal by evaporation, which would entail most of the same problems as tailings disposal in a surface impoundment. Because the slimes fraction of the tailings probably would act to seal the surface of the tunnels it is expected that tailings drainage would be very slow in the mines. Considering that tailings, as discharged from the process circuit, would contain approximately 25 percent solids and 75 percent liquid, on a volumetric basis, and that liquid removal from tailings placed in mines would occur at an unknown but probably slow rate, it would be prudent to plan for storing the entire volume of

solids plus liquids as discharged from the process circuit, rather than storing only about one-third of the total tailings liquid as required for the three other disposal alternatives considered in this analysis.

It is concluded that tailings disposal in the Shootering Canyon mines would not satisfy the NRC performance objective of reducing the potential for groundwater degradation to the maximum extent reasonably achievable.

During Operations

4. Eliminate blowing tailings. Tailings placed in the mines would not be subject to dispersal by wind or moving air, except that radon gas and probably other toxic gases released from the tailings could be distributed by the mine ventilating system or by natural air flows. It is concluded that this performance objective would not be completely satisfied by tailings disposal in the mines.

Post-Reclamation

5. Direct gamma radiation. Tailings disposal in the mines would satisfy the performance objective of limiting gamma radiation from the tailings disposal area to the environs to essentially background levels.

6. Radon emanation. Radon emanation to the atmosphere from tailings placed in the mines would satisfy this performance objective if all the mine openings, ventilation shafts, and exploratory and development boreholes were satisfactorily sealed. The locations of all exploratory borings made in the vicinity over the past 30 to 40 years may not be known, nor is it certain that all earlier borings were properly sealed after completion. If the mine were to be reopened a separate evaluation would be required, based on the conditions prevailing at the time to determine

if the new activity would have the potential for releasing radon from the tailings to the atmosphere. This objective is not completely satisfied under the range of conditions to be considered in this specific case.

7. Need for ongoing monitoring. Once the mines were closed and sealed, and monitoring had established that the seals were performing as intended, there would be no further need to monitor the disposal system. If the mines were to be reopened, monitoring to project the new activity would be required; but this monitoring would not be an ongoing requirement, per se. Reopening of the mine after tailings had been placed in worked out portions of the old mine would constitute an extreme hazard to the miners. Presumably, the new activity would not be undertaken unless it was clear that it could support the costs for monitoring the impacts that the previous tailings disposal system would have on the new activities. It is considered that tailings disposal in the mines would satisfy the NRC performance objective with respect to ongoing monitoring requirements.

8. Financial surety arrangements. Tailings disposal in the mines would be most feasible if the disposal were done concurrently with the ore processing operations. An intermediate or temporary disposal system between ore processing and tailings disposal would greatly increase the disposal costs and difficulties. If tailings disposal were completed as part of the normal project operations, then practically all tailings-related costs would have been incurred before project closure, and the requirements for financial guarantees to complete the tailings disposal reclamation would be minimal. Accordingly, it is concluded that the public exposure to financial risk for tailings disposal closure costs with a mine disposal system would satisfy this NRC performance objective.

The Oil, Gas, and Mining Division of the Utah State Department of Natural Resources requires that operators of mines and ore processing plants in the state obtain a bond to ensure that decommissioning obligations are satisfactorily performed and completed. The amount of this bond will be determined after that agency has reviewed the permit application, reclamation plan, and estimated cost of the reclamation work. Plateau Resources Limited is prepared to execute the necessary bond at the appropriate time.

It is concluded that the State of Utah's bonding requirements would assure that a satisfactory reclamation program of the tailings disposal system would be completed if the project tailings were placed in worked out parts of the project mines. Accordingly, their NRC performance objective would be satisfied with this disposal alternative.

TAILINGS CAPPING REQUIREMENTS

Tailings from the Shootering Canyon ore processing facility would be expected to divide into sand and slimes fractions in the ratio of approximately 4 parts sand (coarser than #200 mesh) to 1 part slimes (finer than #200 mesh). Radionuclides in the tailings would be expected to be concentrated in the slimes fraction, with approximately 80% of the total radioactivity in the 20% of the tailings associated with the slimes. These estimates are based on a sieve analysis and residual uranium analysis of leach residue from the original ore processing facility in Shootering Canyon.

The sand and slimes fractions of the tailings have different capping requirements. Although much of the slimes fraction would be dewatered during the placement procedure and be covered by sand tailings, it appears conservative to assume that at tailings impoundment closure the surface area of the tailings could be divided into portions equivalent to the presumed percentages of slimes and sand, i.e., 20% and 80% respectively. Thus the area of exposed sand would be 0.8 of the impoundment area and the slimes would cover 0.2 of the area.

Assuming an average ore content of 0.10% U_3O_8, 1046 curies of uranium-238 would be processed during an assumed 15-year life of the ore processing facility. For purposes of discussion, the U^{238} is assumed to be in equilibrium with all of its daughters in the ore. Therefore, the radium activity also would be 1046 curies, all of which presumably would be discharged with the tailings.

Estimates by Plateau Resources Limited's engineering contractor indicate that about 8% of the uranium in the ore is insoluble. Consequently, it is assumed that the associated radium is also locked in some crystal form from which its daughter radon cannot escape. Accordingly, 83.7

curies of radium are presumed to be locked in the mineral grains of the tailings and are not mobile. If another 12% of the radium in the tailings is retained in the sand fraction after draining, (in the form of films), then a total of 20% of the radium is present in the sands and 80% in the slimes. On this basis 837 curies, of radium would be contained in the slimes, which is equivalent to 3.67 curies per acre-foot of slime solids (1100 pCi/g). Assuming the density of "dry" slimes to be 1.67, then:

$$C_t = 1837 \text{ pCi/cm}^3 \text{ of bulk medium}$$

where C_t is the concentration of radium-226 in the slimes.

The flux from dewatered slimes may be calculated, assuming a porosity of 40% and a moisture content of 15%, as follows:

$$D_e + \frac{D_a \epsilon}{\xi}$$

where: D_e = effective diffusion coefficient

D_a = diffusion coefficient in air = 0.1

ϵ = porosity = 0.40

ξ = tortuosity, taken here as $\sqrt{3.429}$ (calculated from Tanner*) (the path length for a particle traveling around the tailings grains relative to the net distance between points on the path)

(Values for various conditions are listed by Tanner for the equivalent of D_e/ϵ.)

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*A.B. Tanner, "Radon Migration in the Ground: A Review," in <u>The Natural Radiation Environment</u>, edited by J.A.S. Adams and W.M. Lowder (published for Rice University by the University of Chicago Press, 1964).

Data presented by Tanner indicate that the humidity of the air influences the diffusion as well as the tortuosity and porosity. Above about 9.5%, relative humidity, condensation in fine-grained sand markedly influences the "permeability," and hence the diffusion. For this reason it is necessary to use data from the literature in which representative information is established.

Tanner lists values of De/E for granular materials under different conditions and moisture content; the remaining air-filled void space and the tortuosity (effective) can be calculated from these data. Tanner's values were used as guides for the following calculations.

It appears that the slimes would have most of the essential characteristics of a varved clay when consolidated in the impoundment. It is unlikely that the water content of the slimes would decline much below about 17%, as is typical of clays. The diffusion coefficients for varved clay (0.007) and for fine sand with a 17% moisture content (0.005) are essentially the same. Using the latter figure (because further data are available for fine sand; see Table 1), D_e is 3.512×10^{-4}.

Under these conditions the radon flux , Jz, is calculated by:

$$J_z = -D_e C_v \sqrt{\frac{\lambda}{D_e/\epsilon}} \; e^{-\sqrt{\frac{\lambda}{D_e/\epsilon}}\, z}$$

Where: D_e = effective diffusion coefficient = 3.512×10^{-4}

λ = decay constant of radon 222

= 2.1×10^{-6} per second

ϵ = effective porosity = 0.25

z = distance into slimes from the surface

$Cv = \frac{E\, C_t}{\epsilon} = 1470$

if:

Table 1. SUMMARY OF DIFFUSION COEFFICIENTS (D) REPORTED FOR RADON ISOTOPES IN VARIOUS MEDIA

Diffusing Isotope	Fluid	Medium	D(cm²/sec)	Conditions	Authority
Rn, Tn, An	Air	Continuous	1.0×10^{-1}	Various	Various, quoted in Zimens, 1943
Rn	"	"	1.20×10^{-1}	15° C., 76 cm. Hg	Hirst and Harrison, 1939
"	H_2	"	4.76×10^{-1}	"	"
"	He	"	3.51×10^{-1}	"	"
"	Ne	"	2.17×10^{-1}	"	"
"	Ar	"	9.2×10^{-2}	"	"
"	Alcohol	"	2.69×10^{-5}	18° C.	Róna, 1917, and Ramstedt, 1919, quoted in Zimens, 1943
"	Toluene	"	2.67×10^{-5}	"	"
"	Benzene	"	2.36×10^{-5}	"	"
"	Water	"	1.13×10^{-5}	"	"
"	Air, 4% moisture	Building sand 1.40 gm/cm³, 39% porosity	5.4×10^{-3}	Not stated	Bulashevich and Khayritdinov, 1959
Tn	Air, no moisture	Fine sand (mostly quartz)	6.8×10^{-2}	Not stated	Grammakov, 1936
"	Air, 8.1% moisture	"	5.0×10^{-2}	"	"
"	Air, 15.2% moisture	"	1.0×10^{-2}	"	"
"	Air, 17% moisture	"	5.0×10^{-3}	"	"
Rn	Air	Eluvial-detrital deposits of granodiorite	4.5×10^{-2}	Mean effective value in natural occurrence	Popretinskiy, 1961
"	"	Diluvium of metamorphic rocks	1.8×10^{-2}	"	"
"	"	Eluvial-detrital deposits of granite	1.5×10^{-2}	"	"
"	"	Loams	8.0×10^{-3}	"	"
"	"	Varved clays	7.0×10^{-3}	"	"
"	Air, 37.2% moisture	Mud, 1.57 gm/cm³	5.7×10^{-4}	19°-20° C.	Baranov and Novitskaya, 1949
"	Air, 85.5% moisture	Mud, 1.02 gm/cm³	2.2×10^{-6}	19°-20° C.	"
"	Solid	Barium nitrate	8.0×10^{-20}	Not stated (room temperature)	Strassmann, quoted by Flügge and Zimens, 1939

Source: A. B. Tanner, "Radon Migration in the Ground," in The Natural Radiation Environment, edited by J. A. S. Adams and W. M. Lowder (published for Rice University by the University of Chicago Press, 1964).

E = emanation coefficient, assumed to be 0.2

C_t = concentratin of radium in the slimes

= 1837 p Ci/cm^3 of bulk material

For uncovered slimes, then, at the surface (where z = 0):

$$J_z = (-3.512 \times 10^{-4}) \times 1470 \sqrt{\frac{2.1 \times 10^{-6}}{5 \times 10^{-3}}}$$

$$J_z = (-3.512 \times 10^{-4}) \times 1470 \times 0.020494$$

or $J_z = -0.01058\ pCi/cm^2\text{-sec}$

or $J_z = -106\ pCi/m^2\text{-sec}$

For essentially saturated conditions, in which the diffusion rate is primarily dependent on the rate for radon moving through water:

$$D_e = \underline{D_w} = \frac{(1.13 \times 10^{-5}) \times 0.4}{2} = 3.19 \times 10^{-6}$$

$$D_e = 7.99 \times 10^{-6}$$

$$C_v = EC_t = \frac{0.2 \times 1837}{0.4} = 919$$

$$J_z = (3.19 \times 10^{-6}) \times 919 \sqrt{\frac{2.1 \times 10^{-6}}{7.99 \times 10^{-6}}}$$

$$J_z = 1.50 \times 10^{-3}\ pCi/cm^2\text{-sec}$$

or $J_z = 15.0\ pCi/m^2\text{-sec}$

There would obviously be considerable advantage in keeping the slimes wet for radon control. In practice, it would be desirable to let the slimes dry (drain) at least to the extent that they could support the weight of a blanket of tailings sand. This would allow vertical compression, consolidation, and reduction of porosity. However, reducing the water content below the amount required to fill the pores, in order to produce a physically more stable sedimentary mass is not justified. Slimes enclosure with tailings sand to promote drainage (on the top, sides, and bottom) would prevent the buildup of hydraulic pressure under stress or shock which could result in their liquefaction and flow. If the water transfered to the enclosing sand fractions were removed by drainage, evaporation, or pumping, consolidation of the slimes should be assured, while still protecting them from drying.

Reclamation

For the proposed tailings disposal system, utilizing a natural basin with an impoundment dam, and for the alternatives of disposal in an excavated pit or in a combination pit with above ground containment dike, the requirements for covering the tailings at project termination are the same. It is proposed that the cover would consist of a six feet thick layer of compacted clay to be placed immediately over the tailings. The clay cover would be protected from the atmosphere by a 2 feet thick layer of sandy material, which would in turn be protected from erosion by wind by a one foot thick layer of cobbles, gravel and sand. The following calculations indicate that the proposed cover would satisfy the NRC's performance objective for controlling radon flux from the tailings to approximately twice the background level for the tailings disposal area.

In performing calculations to show the effect of thicknesses of various cover materials in reducing radon flux, the NRC has used the following expression (from their "Bear Creek Cover Calculations"):

$$J_z = J_p^{\,-\sqrt{\frac{\lambda}{D_e/\epsilon}}\; z}$$

where the terms in the equation are as defined above or

$$J_z = J_p - \sum_{i=1}^{n} \sqrt{\frac{\lambda}{D_e/\epsilon}}\; z_i$$

where i defines the particular cover material in a multicomponent cover (n is the number of components).

Using this equation, an estimate can be made of the attenuation of radon by a given cover configuration. Assuming that the cover over the tailings consists of a cap of clay with a D_e/ϵ of 0.007 cm^2/sec (value for varved clay with 17% moisture content, from Tanner) and a surface layer of compacted overburden and local soils with a D_e/ϵ of 0.012 cm^2/sec (10% moisture content), an estimate can be made of the reduction of radon flux through the cover.

Assuming a 6-feet thick clay cap gives 0.0421 for J_z/J_p. A 2-feet thick cover layer of earth materials gives a value of 0.446. Overall, the ratio of radon flux (J_z/J_p) becomes 0.0188, assuming a negligible reduction in radon flux by the top layer of cobble and gravel.

Using the previously obtained value for radon flux from the surface of the compacted slimes as 106 pCi/m^2-sec, and applying the reduction due to the above-described cover, the radon flux at the surface would be 1.99 pCi/m^2-sec (from the buried slimes). This is less than the ambient level

for the area given in the Environmental Report. The sand, which emits much less radon than the slimes, would be the dominant form of tailings at the periphery of the impoundment. Therefore the thickness of the cover could be reduced toward the edges of the impoundment in accordance with good engineering practice, without allowing an undue release of radon.

It is proposed that the above-described 9-feet thick cover be used for planning and surety arrangements, but that appropriate radon flux measurements be performed on the tailings sand and slimes and the clay to be used for the cover at the beginning of reclamation, to guide the final design. At that time, improved radon control technology may be available and modification of the reclamation plan may be desirable.

RADIONUCLIDE MIGRATION

Migration by seepage of radionuclides from the tailings impoundment warrants some special note in that the various disposal alternatives presented in this report range from vertical positioning virtually within the water table (the deep excavation for total disposal below surface) to hundreds of feet above any presently known subsurface aquifer (disposal in the existing mine). Consequently, the rate of movement of radionuclides from the impoundment is of some concern in determining the potential for groundwater contamination over the long term.

As noted earlier, the production rate for the Shootering plant is planned to average 750 tons of ore per day, and the average ore grade is expected to be 0.10% U_3O_8. Accordingly 1046 curies of uranium-238 would be processed during the planned 15-year life of the project. Presuming uranium is in equilibrium with its daughters, the radium activity also would be 1046 curies. Approximately 150 gallons per minute of liquid will accompany the tailings as they are moved from the plant to the impoundment. It has been estimated that 90% of the uranium content in the ore will be recovered by the mill process. Eight precent of the uranium in the ore is essentially refractory (i.e. insoluble or locked up in the crystal grains), and the remaining 2% of the uranium lost to the tailings is contained in the tailings colloids or in liquid films surrounding the solid particles of the tailings. Thorium-232 content of the ore is believed to be so low as to be of little consequence in this analysis.

The factors that affect the potential migration rate of radionuclides from the impoundment by means of seepage include:

1) The relative velocity of the seepage water

2) The dispersion coefficient(s)

3) The retardation coefficient(s)

Design specifications for lining thicknesses include factors such as changing head in the impoundment over the years of operation. Obviously, seepage rates will vary depending on the head, capillary holding capacity of the tailings, and tailings management practices (particularly dewatering and consolidation of the slime fraction). Sears[1] evaluated a model based on lining materials and underlying soils having similar velocity characteristics to those of the Shootering materials. However, Sears presumed a radionuclide loss rate higher than has been measured at any known existing tailings impoundment. Since the dispersion coefficient essentially acts to decrease radionuclide concentrations, only the velocity of the seepage water and the effective retardation coefficients were used in the analysis. Sears used retardation coefficients of 100 for Ra-226 and greater than 1000 for uranium and thorium. As a result he determined that the 10% concentration contour for radium would be only 3 meters below the base of the pond after a period of 20 years; similarly the 10% concentration contours for uranium and thoruim would be about 2 meters below the impoundment bottom after 20 years.

The retardation coefficients (Kd's) used by Sears appear to be rather low; reflecting, perhaps, the type of sands used in developing

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[1] Oak Ridge National Laboratory (ORNL). May 1975. 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, M.B. Sears, R.E. Blanco, R.C. Dahlman, G.S. Hill, A.D. Ryon, and J.P. Witherspoon. National Technical Information Service. Springfield, Virginia.

his generic model. Battelle[2] evaluated the Kd's for soil similar to those at Yucca flats, and concluded that, for sandy desert soils of about 5 meq/100g ion exchange capacity, and containing about 1 mg/g of $CaCO_3$ and having a soil pH of 7.0 to 8.2, the retardation coefficients should be larger, viz. 14,300, 50,000 and 500 for uranium, thorium and radium,[3] respectively. The result of changing the coefficients to these values has the effect of decreasing migration rates, so that distances of migration calculated by Sears would take place over millenia rather than within 20 years.

As may be seen in Appendix B of the Environmental Report, the ion exchange capacity of the surface and near surface soils at the Shootering site was determined to be about 20 meq/100 grams. In addition, substantial layers of caliche (largely $CaCO_3$) exist within the near-surface soils and at various levels of the underlying rock. While apparently formed by archaic groundwater systems that no longer exist, these concentrations of caliche would act to further retard the migration of radionuclides, and would assure neutralization of the tailings seepage. The relatively high ion exchange capacity of the Shootering soils (and the even higher capacity of the proposed silt/clay liner) also would act to reduce the migration rate of the radionuclides.

Comparison of the proposed impoundment at the Shootering site with Sears model, therefore, warrants the conclusion that the advantages provided in the proposed site, and subsequent design specifications, provide

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[2]Battelle Northwest Laboratories (BNWL). 1975. High-Level Radioactive Waste Management Alternatives, BNWL-1900, Richland, WA., K.J. Schneider and A.M. Platt, eds.

[3]Retardation coefficients of most of the radium daughters are on the same order as the uranium and thorium coefficients, i.e., in excess of 1000.

more than adequate long term control of radionuclide migration associated with tailing liquid seepage from the impoundment. As noted earlier, after conclusion of the milling activities and final dewatering of the tailings, potential for seepage from the impoundment would become negligible and further migration of radionuclides should, for all intents and purposes, cease.

CONCLUSIONS

The conclusions of the preceding discussion, with respect to the degree to which each of the tailings disposal alternatives would satisfy each of the NRC staff's performance objectives, are summarized in Table 2. Ranking as indicated in the table is with respect to the individual objectives. The rankings merely indicate where there are differences in the extent to which the various disposal alternatives satisfy the various objectives, without attempting to quantify the extent of the differences. Where two or more alternatives are assigned an equal rank with respect to an objective there were no identified differences in the extent to which the objective would be satisfied by the alternatives assigned equal rank.

Based on the rankings indicated in the table and the preceding supporting discussions, it is concluded that the proposed natural basin with impoundment dam most nearly satisfies all of the NRC performance objectives among the disposal alternatives identified as being potentially feasible for the proposed Shootering Canyon project. The proposed disposal plan embodies practically all the merits of a fully buried disposal facility, without encountering the problems of penetrating the natural groundwater surface in the area as would happen if a fully buried disposal system were to be developed for the project.

Preliminary estimates of the capital costs required to develop disposal alternatives 1, 2 and 3 were prepared by Mountain States Engineers. Those estimates are summarized in Table 3. As mentioned above in the section "Disposal Alternatives" the operating costs for the 3 alternatives were assumed to be equivalent.

No costs are presented for alternative 4, disposal in the mines, because it was concluded that tailings disposal in the Shootering

Table 2. RANKING OF TAILINGS DISPOSAL ALTERNATIVES ACCORDING TO NRC PERFORMANCE OBJECTIVES

Performance Objective	Disposal Alternative			
	Natural Basin with Impoundment Dam	Excavated Pit	Combined Pit and Containment Dike	Return to Mine
1. Remote from people	1	1	1	2
2. Probability of dispersal by natural forces	2	1	2	3
3. Probability of seepage to groundwater	1	4	2	3
4. Blowing of tailings during plant operation	1	1	1	1
5. Reduction of gamma radiation to background level	1	1	1	1
6. Reduction of radon emanations to twice the background level	1	1	1	2
7. No need for ongoing monitoring	2	1	2	1
8. Surety arrangement provided for closure	1	1	1	1

Table 3. ESTIMATED CAPITAL COSTS TO DEVELOP ALTERNATIVE TAILINGS DISPOSAL SYSTEMS

Alternative	Cost
1. Natural basin with impoundment dam	$11,100,000
2. Excavated pit	31,400,000
3. Combination pit and containment dike	27,900,000
4. Return to mine	No estimate

Canyon mines would not be feasible. Mine disposal would present an unacceptable and unnecessary hazard to the project mine workers. Also, mine disposal could preclude the recovery of low grade ores in the vicinity if future economic conditions made their recovery otherwise feasible.