Evaluation of Tailings Disposal Alternatives Shootering Canyon Uranium Project, Utah

for

Plateau Resources Ltd.
Grand Junction, Colorado

November 1978

7812050345

60265A

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

Three Embarcadero Center, Suite 700
San Francisco, California 94111
415-956-7070

Woodward-Clyde Consultants

DOCKET NO. 40-8698

November 15, 1978

Mr. R.B. Sewell
Plateau Resources Limited
772 Horizon Drive
Grand Junction, Colo. 81501

Dear Mr. Sewell:

Enclosed is our report "Evaluation of Tailings Disposal Alternatives, Shootering Canyon Uranium Project, Utah".

This report was prepared in response to a request from the Nuclear Regulatory Commission submitted to Plateau Resources Limited in their letter of July 6, 1978. The NRC provided a copy of a report "Evaluation of Long Term Stability of Uranium Mill Tailings Disposal Alternatives" prepared by J.D. Nelson and T.A. Shepherd, Colorado State University, April 1978. Tailings disposal alternatives considered for the Shootering project are reviewed in our report with respect to the potential failure modes discussed in the Nelson and Shepherd report, and as requested by the NRC.

Sincerely,

M B Bennedsen

M.B. Bennedsen
Senior Project Manager

enc

11267

Evaluation of Tailings Disposal Alternatives Shootering Canyon Uranium Project, Utah

for

Plateau Resources Ltd.
Grand Junction, Colorado

November 1978

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

60255A

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

This study was conducted by the Decision Analysis Group, Environmental Systems Division, Woodward-Clyde Consultants. Dr. Keshavan Nair was project director. Mr. Alan Lamont and Dr. Fereidoon Sioshansi were principal analysts, Dr. Sam Bannerjee assisted on geotechnical issues, and Dr. Jerry Champlin advised on radiological and hydrological issues.

disposal in the mines from the analyses. The three disposal alternatives evaluated in this study are:

1. Natural basin with impoundment dam
2. Fully excavated pit
3. Combination excavated pit and containment dike

These estimates have been made largely on a qualitative basis, since the state of the art does not realistically permit quantitative analysis of many of the phenomena involved, particularly considering the extremely long time frames used.

1.1.1 Evaluations Made by this Study

The analysis provides an assessment of the levels of risk associated with the alternatives and evaluates the acceptability of the risks. In evaluating the alternatives, it is recognized that safety is of paramount importance, particularly from the point of view of the public. For this reason an evaluation based on safety alone has been made. Making such an evaluation involves some value judgments, however, since no single alternative was clearly superior to the others in all respects. A second evaluation including additional criteria, particularly cost effectiveness, was also made. Such a comparison provides a more complete view of what is to be gained or lost by accepting one alternative over another.

1.1.2 Bases for the Evaluation

To evaluate alternative tailings disposal plans, it is necessary to define both the objectives that a tailings disposal plan should meet and

1.0 INTRODUCTION AND CONCLUSIONS

1.1 INTRODUCTION

This study has been prepared in response to a request from the Nuclear Regulatory Commission (NRC)* that the alternative tailings disposal plans considered for the Shootering Canyon Uranium Project be evaluated with respect to various potential failure modes. To meet this request, the alternative plans described in the Tailings Management Plan (Woodward-Clyde Consultants, 1978a) have been examined to determine the types of radionuclide releases that are likely to occur from each, the amounts of radionuclides that might be released, the possible timing of the releases, and the relative likelihood that these releases might actually occur.

It is noted that the Tailings Management Plan (WCC, 1978a) included consideration of underground disposal of tailings by returning them to the mines. However, that disposal technique was found to be significantly inferior to the other techniques considered in that study. Accordingly, for this study it was considered appropriate to omit underground

*Letter from NRC to Plateau Resources Limited, July 6, 1978.

the physical events which will influence the degree to which the objectives are met. The NRC (1977) has developed a set of eight specific performance objectives to be used in evaluating tailings disposal plans:

1. Locate the tailings isolation area remote from people such that population exposures would be reduced to the maximum extent reasonably achievable.

2. Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

3. Design the isolation area such that seepage of toxic materials into the groundwater system would be eliminated or reduced to the maximum extent reasonably achievable.

4. Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

5. Reduce direct gamma radiation from the impoundment area to essentially background.

6. Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

7. Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

8. Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan.

Of these eight objectives, Nos. 1, 4, 7, and 8 were found to be met equally by all disposal alternatives under consideration. The remaining four objectives have been taken into account in the evaluation process reported in this study.

When the NRC requested that this study be made, the report "Evaluation of Long-Term Stability of Uranium Mill Tailings Disposal Alternatives" by John D. Nelson and Thomas A. Shepherd (1978) was provided as a guide. All possible failure modes discussed in that report have been considered here.

1.2 CONCLUSIONS

The principal conclusions of this study are summarized as follows:

1. The time frame of concern is approximately 15,000 years. At the end of 15,000 years, the radioactivity of Shootering project tailings is expected to have decayed to essentially the level of radiation attributable to the residual uranium in the tailings, which would be approximately equal to the level of radiation found in exposed soils and rock in the project vicinity.

2. For the natural basin with impoundment dam and the combination pit with containment dike alternatives, the only important concerns would be erosion by rainfall and runoff at the surface of the dam or dike and, ultimately, dispersion of the tailings.

3. For the fully excavated pit alternative, the principal concern would be leaching of radionuclides to the groundwater, with possible localized contamination of the groundwater. Contamination might occur soon after initial placement of tailings in the containment, due to the proximity of the pit bottom to the groundwater level.

4. The cobble and gravel armor to be placed on exposed surfaces of the impoundment dam or the containment dike would be expected to be resistant to erosion for several thousand years. Assuming the armor were removed, it would take several thousand additional years for erosion to progress through the body of the dam or the dike to the extent that tailings would be exposed and subject to erosion. No significant tailings dispersal would be expected in the 15,000-year time frame of concern for the natural basin with impoundment dam and the combination pit with containment dike alternatives.

5. Tailings in any of the containments considered would be expected to undergo a chemical stabilization process during the first few decades after placement. The basic stabilization process would by crystal growth of the calcium sulfate distributed throughout the tailings mass by the placement procedures. The result would be to cement the tailings into a solid mass having a resistance to erosion similar to or greater than the natural sandstones in the area.

6. Assuming that tailings were exposed and subject to dispersal, the forces available for their dispersal would be limited by the quantity of runoff acting on the exposed surfaces. The arid climate of southeastern Utah and small drainage areas contributing runoff across the tailings would limit tailings dispersal to small amounts.

7. If tailings were released from any of the containments considered, they would be mixed and diluted with other sediments in Shootering and Hansen creeks. Dilution ratios of 1 part tailings to at least 400 parts other sediments would be expected.

8. All three disposal alternatives evaluated would be considered to satisfy the NRC performance objectives for tailings disposal over both the short and the long term.

9. Evaluation of the relative desirability of the various disposal alternatives requires the inclusion of other relevant factors, including cost-effectiveness. On this basis it is concluded that the natural basin with impoundment dam is preferable to the other two disposal alternatives considered. The fully excavated pit alternative represents a substantially greater cost than the preferred alternative, with no clear increase in safety. The combination pit and containment dike also would be substantially more costly than the preferred alternative, while offering little if any increase in safety.

2.0

APPROACH

This study approaches the evaluation of tailings disposal plans based on consideration of the following factors:

- identification of possible failure and release modes for each of the tailings disposal alternatives considered,*
- the likelihood of occurrence of possible failure and release modes,
- the magnitude and rate of release of material in the event that failure occurs,
- estimation of the time at which release may commence, and
- probable consequences of a potential release given a particular mode of failure.

The primary purpose of this report is to analyze these factors for each of the alternatives. Evaluation of their absolute or relative desirability can then be made. Such evaluations depend on value judgments about the relative importance of the many factors present. An attempt has been made to separate the factual results of the analysis from personal judgments as far as possible.

---

*See Section 3.0.

An important aspect of the present approach was the identification of those issues which differentiate the alternatives and are important to their evaluation. The first part of the analysis (Section 4.1) reviews the concerns raised in the Nelson and Shepherd report. Through physical reasoning, their list of 28 modes of failure was condensed to 15 separate events that could cause releases of radionuclides.

An appropriate set of time frames was defined for the present study (Section 4.2). Furthermore, each event was examined in its relevant time frame and analyzed with regard to its probability of occurrence leading to a failure mode, the time at which a given type of release might be expected, and its potential consequences.

The different possible releases were grouped under three release modes: gaseous (radon) releases, releases of dissolved radionuclides to the groundwater, and above-ground releases of primarily undissolved (solid) radionuclides (Section 4.3). This last release mode would also result in some release of dissolved and gaseous radionuclides and some gamma ray emissions.

The specific geotechnical and climatic conditions prevailing at the Shootering Canyon site were then investigated (Section 4.4). Many of the events listed in Nelson and Shepherd (1978) were found to have little impact on the comparison of the alternatives because they were unlikely to occur (compared with the other events), because the likelihood of their occurrence was equally small for all alternatives, and/or because

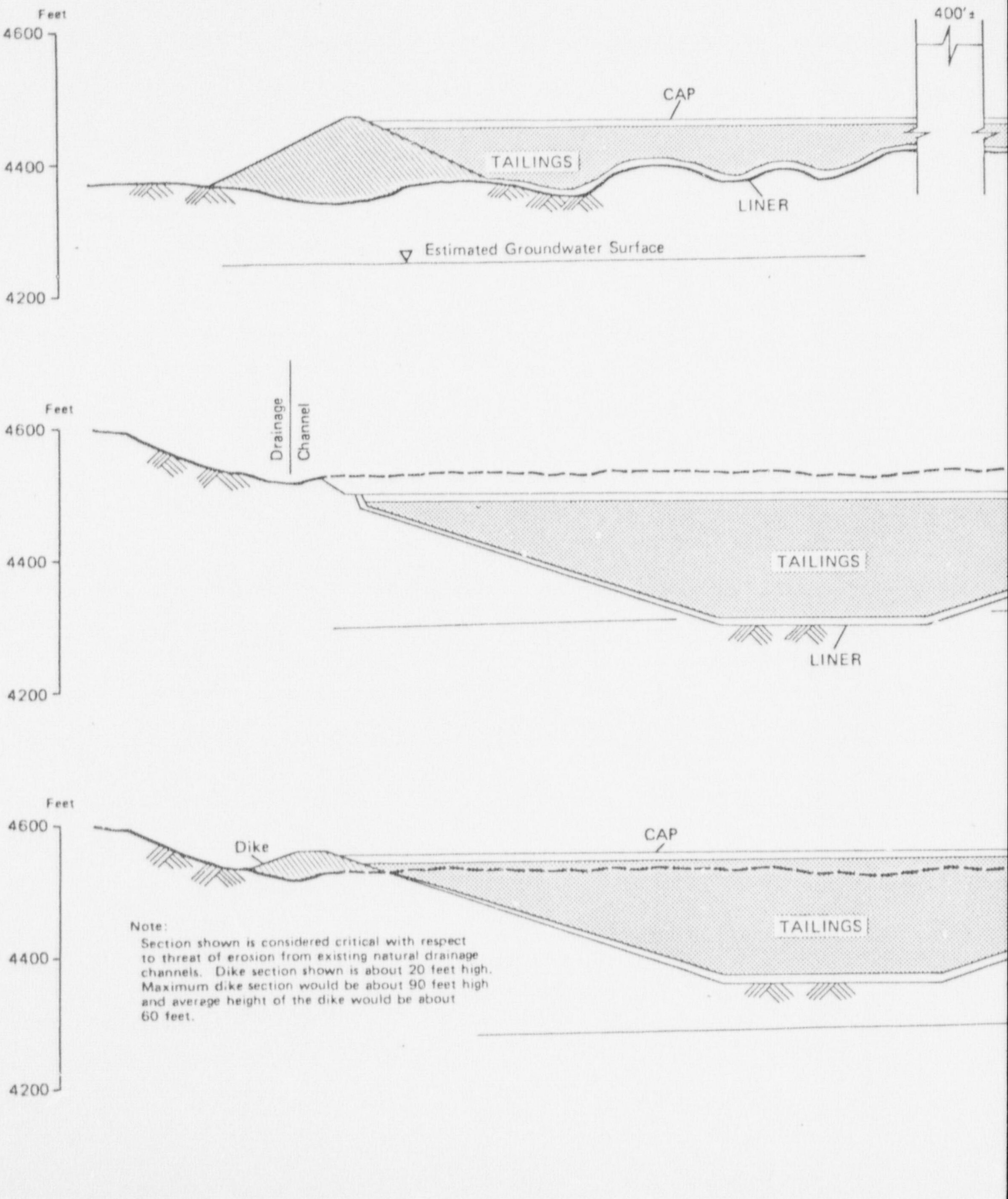
the consequences of their occurrence were relatively unimportant. It therefore became apparent that the comparison of the alternatives could be based on the likelihood of occurrence and the consequences of only a few events. In other words, the entire evaluation process could be carried out by focusing attention on only a subset of issues.

From the analysis, an understanding of the relative susceptibility of, and the risks associated with, each alternative emerged. Using this information, the alternatives were evaluated. It was determined that if safety were the only evaluation criterion, no alternative could be considered superior to all others in all aspects. Therefore, a strict ranking of the alternatives would require that value judgments be made on the relative significance of the differences, or tradeoffs. The present study has attempted to avoid such judgments whenever possible; rather, an effort has been made to present the tradeoffs clearly so that the reader may apply his judgment to the significance of those tradeoffs.

3.0

ALTERNATIVES CONSIDERED

Four tailings disposal methods were originally considered for the Shootering Canyon Uranium Project (Woodward-Clyde Consultants, 1978a). Of these four, the underground disposal alternative (which required that the tailings be returned to the mine) was dismissed as unacceptable because of certain deficiencies (WCC, 1978a, pp. 58-61) and is not considered here. The three remaining alternatives considered in this report are shown schematically in Figures 1 and 2. These figures are provided to focus attention on the relative susceptibility of each disposal alternative to the various basic events (to be defined in the following section). More detailed descriptions of the alternatives are provided elsewhere (Woodward-Clyde Consultants, 1978a), and are not repeated here.



Feet
4600
4400
4200
400'±
CAP
TAILINGS
LINER
Estimated Groundwater Surface
Feet
4600
4400
4200
Drainage Channel
TAILINGS
LINER
Feet
4600
4400
4200
Dike
CAP
TAILINGS
Note:
Section shown is considered critical with respect to threat of erosion from existing natural drainage channels. Dike section shown is about 20 feet high. Maximum dike section would be about 90 feet high and average height of the dike would be about 60 feet.

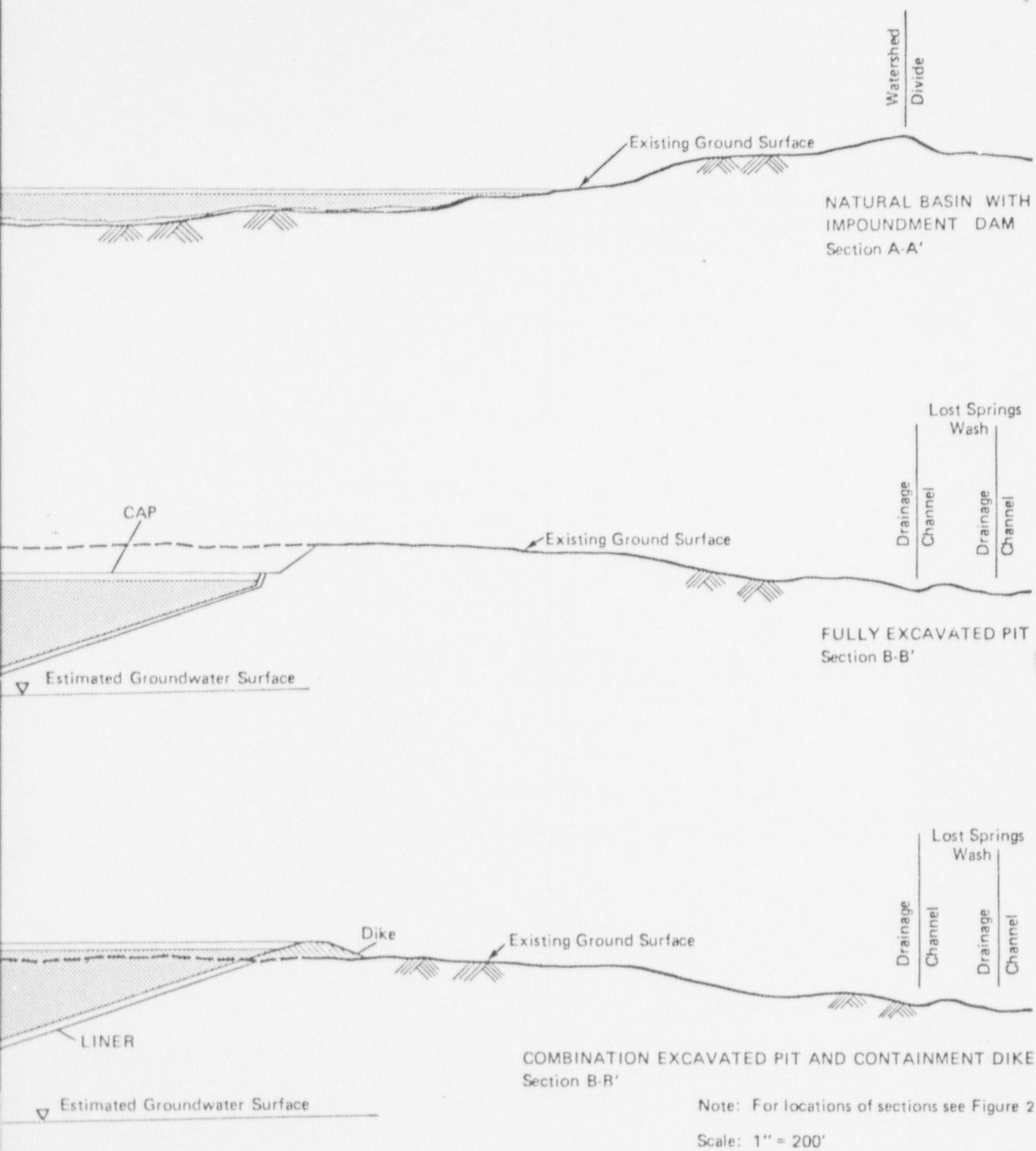


Figure 1. REPRESENTATIVE SECTIONS THROUGH ALTERNATIVE TAILINGS DISPOSAL FACILITIES

APPROXIMA
BOUNDARY
PROPOSED
TAILINGS
POND
A

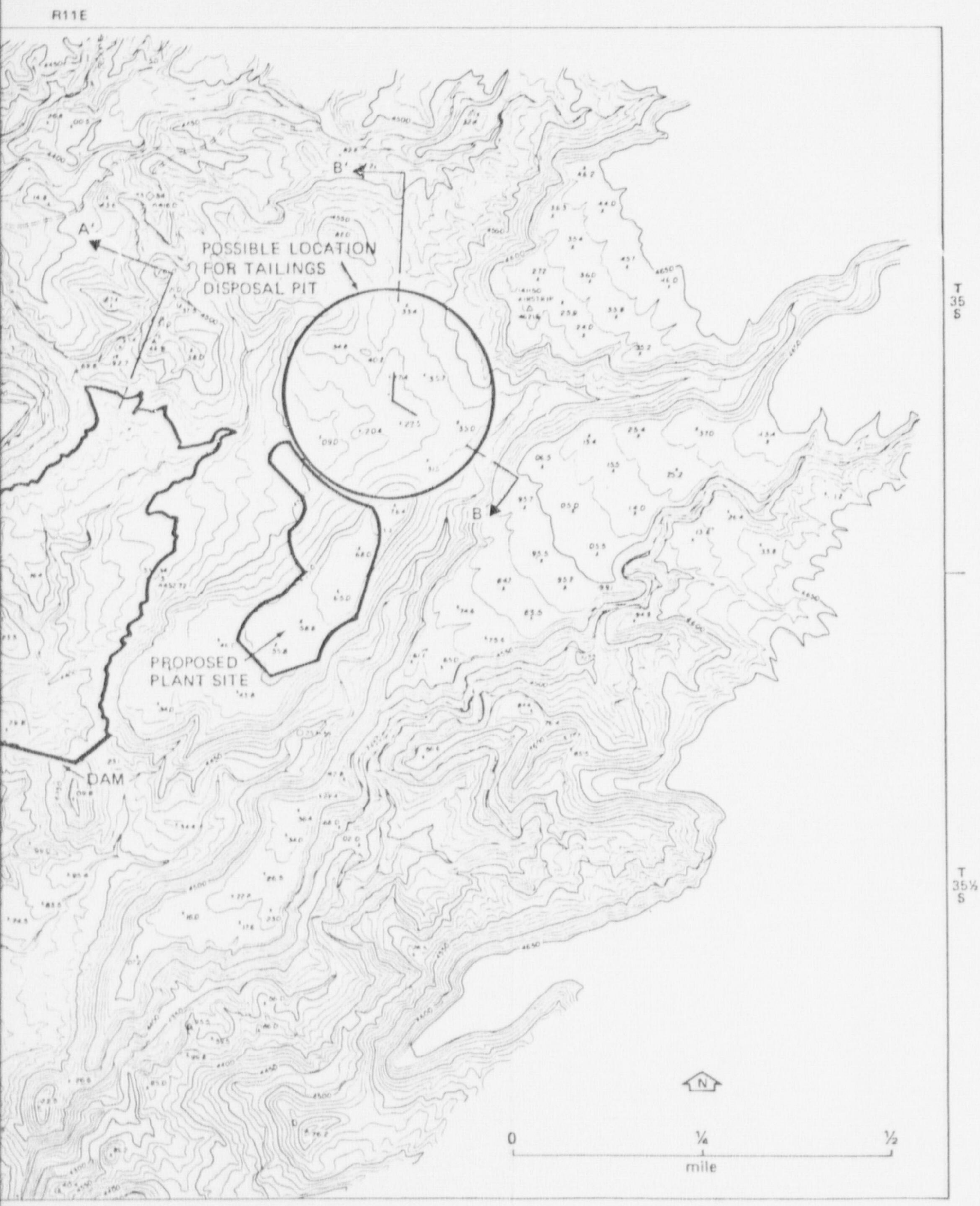


Figure 2. Shootering Canyon uranium project tailings disposal study: Locations of impoundment pond and pit disposal alternatives

4.0

STRUCTURING THE ANALYSIS

This section describes the development of a structure for analyzing the likelihood of the various events that might lead to a release of radionuclides and for determining those events which are most important to the overall analysis. To this end the concepts of basic events, short-run (SR) and long-run (LR) time frames, and modes of release are defined.

4.1 BASIC EVENTS

Basic events are defined as natural events or processes which might occur at the site and might lead to the release or exposure of tailings material. An explicit requirement of this study was that all of the possible failure modes considered by Nelson and Shepherd (Table 1) be addressed. These failure modes were used as the starting point in developing the set of basic events used in this study. Later in this section the correspondence between the basic events and the failure modes considered by Nelson and Shepherd (1978) is discussed in detail.

Under Nelson and Shepherd's formulation many natural events are considered several times under different headings. For example,

TABLE 1. MODES AND MECHANISMS OF FAILURE IDENTIFIED BY NELSON AND SHEPHERD

A. ELEMENTAL

1. CAP
   a) DIFFERENTIAL SETTLEMENT
   b) GULLYING
   c) WATER SHEET EROSION
   d) WIND EROSION
   e) FLOODING
   f) CHEMICAL ATTACK
   g) SHRINKAGE

2. LINERS
   a) DIFFERENTIAL SETTLEMENT
   b) SUBSIDENCE OF SUBSOIL AND ROCK
   c) CHEMICAL ATTACK
   d) PHYSICAL PENETRATION

3. EMBANKMENT
   a) DIFFERENTIAL SETTLEMENT
   b) SLOPE FAILURE
   c) GULLYING
   d) WATER SHEET EROSION
   e) WIND EROSION
   f) FLOODING
   g) WEATHERING AND CHEMICAL ATTACK

4. REVEGETATION
   a) FIRE
   b) CLIMATIC CHANGE

5. WATER DIVERSION STRUCTURES
   a) SLOPE FAILURE
   b) OBSTRUCTION

B. NATURAL PHENOMENA

1. EARTHQUAKES
2. FLOODS
3. WINDSTORMS
4. TORNADOES
5. GLACIATION
6. FIRE AND PESTILENCE

Source: Nelson & Shepherd (1978)

water sheet erosion, wind erosion, gullying, and floods are discussed as working on the cap and on the embankment separately. Clearly, these events will most likely affect both elements simultaneously, and with similar results. For example, it is difficult to conceive of a flood that affects the cap but not the embankment.

In order to analyze the likelihood of various failures effectively, it is preferable that each natural event appear only once in the set of events to be considered. This simplifies the analysis of failure likelihoods and avoids redundancy. The possible releases resulting from each natural event can then be analyzed separately.

In view of these considerations, a simplified set of "basic events" was developed and is presented in Table 2. The simplified set includes all the events discussed by Nelson and Shepherd, except for few events that were clearly not relevant for the alternatives under consideration. This set also includes two events (seepage to groundwater, and groundwater movement through the tailings) not mentioned by Nelson and Shepherd that are relevant to the Shootering Canyon Project. The following discussion cross-references the two lists to show how each of Nelson and Shepherd's failure modes has been accounted for:

- Differential settlement of the cap (A.1.a in Table 1) is considered as differential settlement of the tailings (1 in Table 2).
- Gullying of the cap (A.1.b) and embankment (A.3.c) are combined under gullying (10).

Table 2. BASIC EVENTS

1.	Differential settlement of the tailings
2.	Shrinkage of the cap
3.	Chemical attack on the cap
4.	Seepage of tailings liquid to groundwater
5.	Groundwater movement through tailings
6.	Differential settlement of subsoil and subsidence
7.	Chemical attack on the liner
8.	Physical penetration of the liner
9.	Static slope failure
10.	Gullying
11.	Floods
12.	Earthquakes
13.	Glaciation
14.	Tornadoes and severe wind storms
15.	Wind erosion

- Water sheet erosion of the cap (A.1.c) and embankment (A.3.d) would quickly lead to gullying; therefore, they are included under gullying (10).

- Wind erosion of the cap (A.1.d) and embankment (A.3.e) are combined as wind erosion (15).

- Flooding of the cap (A.1.e), embankment (A.3.f), and floods (B.2) are all considered under floods (11). There is no compelling reason to consider floods under both elemental phenomena and natural phenomena.

- Chemical attack on the cap (A.1.f) is considered (3).

- Shrinkage of the cap (A.1.g) is similarly considered (2).

- Differential settlement of the liner (A.2.a) and subsidence of the subsoil and rock (A.2.b) are taken into account under differential settlement of the subsoil and subsidence (6).

- Chemical attack on the liner (A.2.c) is considered (7).

- Physical penetration of the liner (A.2.d) is considered (8).

- Differential settlement of the embankment (A.3.a) is considered under (6).

- Slope failure (A.3.b) is considered under static slope failure (9) to distinguish this mode from gradual slope failure due, for example, to water erosion.

- Gullying (A.3.c), water sheet erosion (A.3.d), wind erosion (A.3.e), and flooding of the embankment (A.3.f) were already discussed.

- Weathering of and chemical attack on the embankment (A.3.g) are not considered as failure modes in themselves but as conditions leading to or speeding other basic events, such as wind and water sheet erosion. For this reason, they are not considered separately.

- Because no vegetation cover was considered for the presently proposed tailings impoundment, it is not necessary to consider fire (A.4.a) and climatic change (A.4.b). Both events, however, are implicitly considered under wind and water erosion because that is where their effects ultimately will be felt.

- Slope failure (A.5.a) and obstruction (A.5.b) of the water diversion structures are not included in Table 2 since these are not events which would cause failure by themselves but are events that would contribute to the likelihood of gullying or failure by flooding.

- Earthquakes (B.1) are considered under (12).

- Glaciation (B.5) is considered (13).

- Severe wind storms (B.3) and tornadoes (B.4) are combined because of their similarities (14).

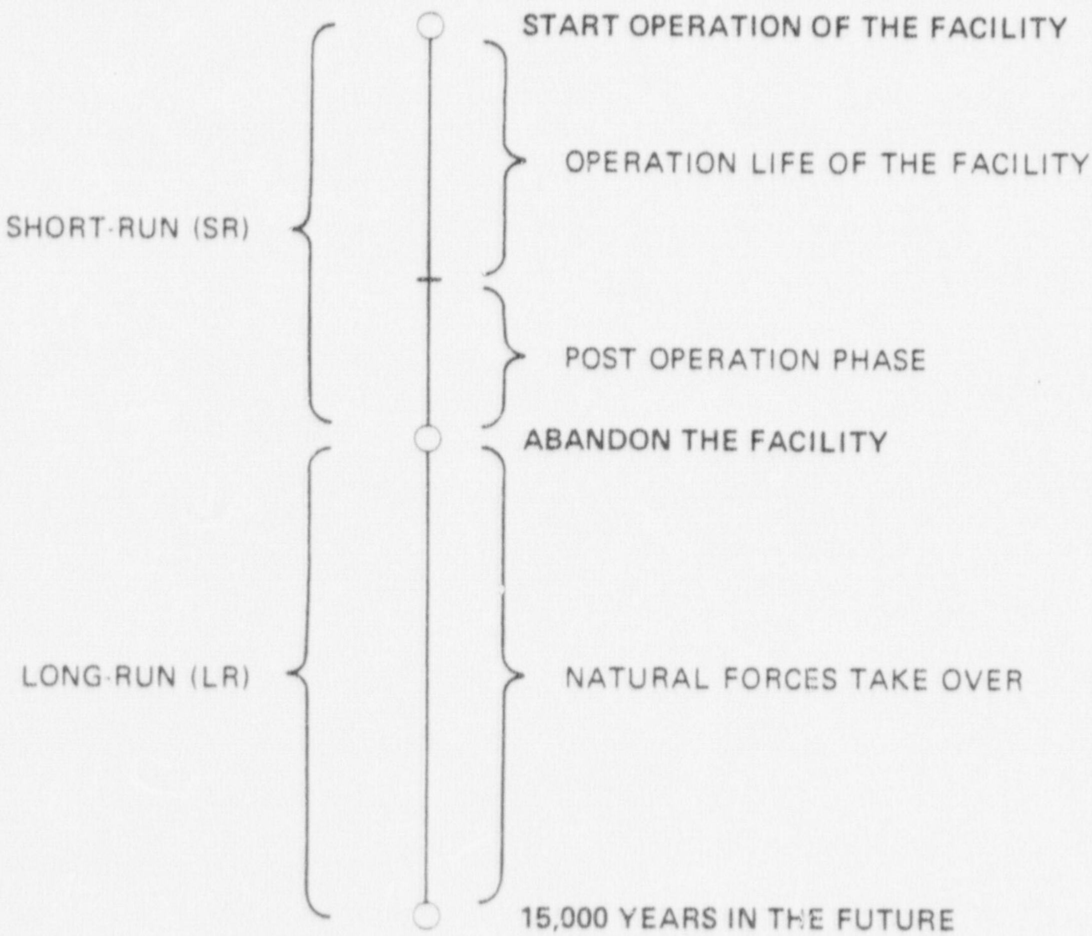
- Fire and pestilence (B.6) are seen as contributors to other failure modes but are not considered as problems in themselves.

4.2 TIME FRAMES

For the purposes of this study, it was helpful to define two time frames, short-run (SR) and long-run (LR). The SR covers the period of time from the beginning of the facility's operation to its abandonment. Accordingly, the SR can be divided into two sub-periods: the operation period and the post-operation period (Exhibit 1). For the particular facility being considered here, the sub-periods are estimated to be about 20 years and 5 years, respectively. The LR is defined as the length of time after abandonment to roughly 15,000 years.

These definitions of SR and LR are based on consideration of the planned operation and maintenance of the facility and the decay rate of the tailings. Abandonment of the facility is a natural breaking point between the two periods, because it is at that time that the facility is left to natural forces, and no active monitoring, inspection, or upkeep is assumed.

EXHIBIT 1. SHORT-RUN (SR) AND LONG-RUN (LR) TIME FRAMES



In order to define the LR time frame in a meaningful manner, it is necessary to define a significant point in the life of the tailings after abandonment. An important milestone in the life of the tailings is the time at which the total level of radioactivity approaches that of the "permanent" base level radiation. The significance of this statement can be seen from an observation of Figure 3, which schematically shows the total level of radioactivity of the tailings as a function of time. The "permanent" base level radiation is defined as the level of radioactivity from that uranium contained within the grains of sand that was not extractable by the mill process.

Because of uranium's slow decay rate (the half-life of U-238 is approximately $4.5x10^9$ years), its level of radioactivity will be essentially constant throughout the long term as considered in this analysis - hence, the term "permanent" base level radiation. Included in this definition are the uranium daughters, which are bound within the sand grains with the uranium and which remain in equilibrium with the parent uranium. The daughter products of uranium - e.g., thorium 230 and radium 226 - have relatively fast decay rates compared with that of the uranium. (Radium 226 has a half-life of 1620 years.) Processing of the ore removes most of the uranium, but the majority of the uranium daughters remain in the tailings. Therefore, processing of the ore removes little of the contained radioactivity. However, with little uranium present in the tailings to keep forming new daughters, the radioactivity of the tailings will decrease exponentially over time. At any given time, therefore, the

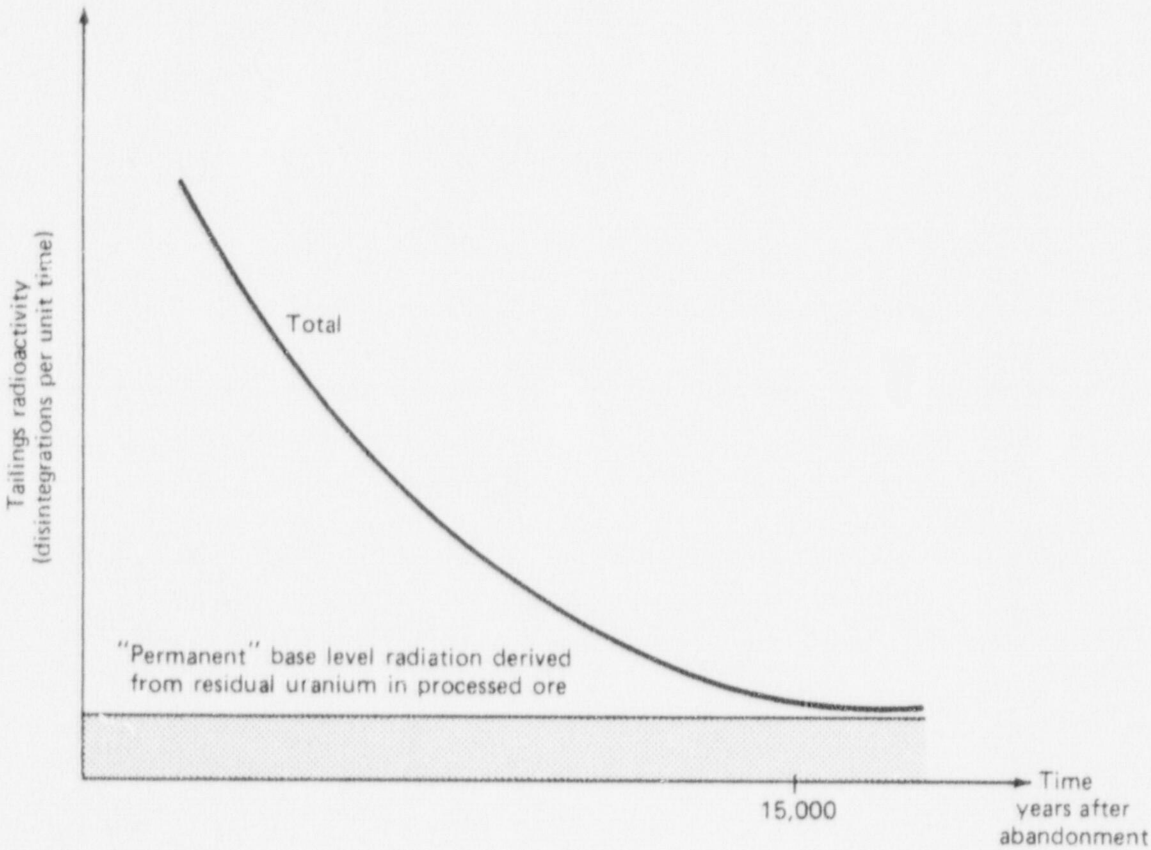


Figure 3. REPRESENTATIVE DECAY CURVE FOR RADIOACTIVITY OF TAILINGS

total level of uranium-based radioactivity in the tailings will be the sum of the radioactivities of the residual uranium and its daughters contained in the sand grains and the daughter products of uranium which were not removed by the mill process.

As shown diagrammatically in Figure 3, in approximately 15,000 years, the level of radioactivity in the tailings approaches a level which is roughly equal to that of the "permanent" base level of radiation (see Appendix B). After this point, the decay rate of the uranium contained in the sand grains becomes the dominant factor. Hence, the significant point in the life of the tailings is approximately 15,000 years and not 100,000 years (as used by Nelson and Shepherd) or some other arbitrary number. Needless to say, 15,000 years (as opposed to 100,000 years) is a much more manageable length of time with which to deal.

Using these time frame definitions, each of the basic events can be classified as either SR or LR. A SR event (such as differential settlement) will occur (or at least begin) during the operating life of the facility or shortly thereafter. If it does not occur (or begin) in the SR, then it is unlikely that it will ever occur. A LR event, on the other hand, could manifest itself at any time. The fact that it has not occurred during the first 25 years of the facility's operation does not rule out the possibility that it could occur at a later time (Exhibit 2).

EXHIBIT 2. DISTINCTIONS BETWEEN TIME FRAMES

SHOR-RUN (SR)

- "ACTIVE" MONITORING AND INSPECTION OF THE IMPOUNDMENT IS ASSUMED
- SHOULD ANY FAILURE MODES OCCUR DURING THIS PERIOD THEY WILL BE DETECTED
- ANY INCIPIENT MODES OF FAILURE WILL BE RECOGNIZED
- MAINTENANCE AND UPKEEP OF THE FACILITY IS REQUIRED
- REMEDIAL MEASURES WILL BE TAKEN SHOULD SUCH ACTIONS BE NECESSARY

LONG-RUN (LR)

- NO "ACTIVE" MONITORING, INSPECTION OR MAINTENANCE CAN BE ASSUMED
- CERTAIN BASIC EVENTS ARE NOT LIKELY TO OCCUR IF THEY HAVE NOT ALREADY HAPPENED OR STARTED
- NATURAL FORCES WILL TAKE OVER
- CERTAIN EVEN[illegible]LY TO OCCUR AT "RAND[illegible]
- OTHER EVENTS WILL "GRADUALLY" TAKE PLACE

The distinction between SR and LR events is significant for two reasons. First, the consequences of SR events may be much less severe because such events are likely to be detected in their early stages, when appropriate remedial actions can be taken expeditiously and inexpensively. Therefore, the probability of SR events leading to significant consequences tends to be low and is roughly equal for all alternatives.

Second, the approach for analyzing SR events is quite different from that for analysis of LR events. A SR event either will or will not occur with some fixed probability. A LR event, on the other hand, will almost undoubtedly occur eventually; the primary problem is estimating when it will occur. Obviously, some events (e.g., floods) could occur in the SR as well as in the LR, but the probability that they will occur in the SR is much smaller than the probability that they will occur in the LR. Thus they are basically LR events.

4.3 RELEASE MODES

In order to describe the consequences of any given failure, we have defined the following modes of release:

- Gaseous releases - implies a failure of the cap resulting in release of radon gas (a small amount of gamma rays may also be released).
- Release to the groundwater - implies the movement of dissolved radionuclides from the impoundment into groundwater.
- Release on the surface - implies the cap and/or embankment (if any) no longer confines the tailings and they are (or may be) dispersed by wind or water. This also implies releases of radon gas and gamma ray emission.

• Gamma ray emission - implies a partial or complete failure of the cap and exposure of the tailings material.

These definitions are consistent with NRC objectives listed in Section 1.0 and with the analysis developed by Nelson and Shepherd.

The consequences of any failure can be quantified according to the amount of radionuclides (primarily radon and radium) released by each mode. This in turn allows one to judge the relative desirability (or undesirability) of a failure, taking into account the pathways to man and other life forms implied by each of these release modes.

Each of the basic events is linked to one of the release modes, as shown in Table 3. Therefore, the likelihood that a release would occur through a particular mode is equal to the likelihood that one or more of the corresponding basic event would occur. It must be pointed out that two or more release modes may occur simultaneously. For example, problems in the liner (leading to release of dissolved radionuclides to the groundwater) and the cap (leading to gaseous releases) may be present at the same time for certain alternatives.

In absolute terms, none of the four release modes described above is considered to be a source of concern for the three tailings disposal alternatives evaluated. (The analysis of the alternatives is presented in Section 5.0.) Adequate design considerations and the location of the facility are the two major reasons. Consequently, only minor relative differences remain to be considered in a discussion of the potential modes of release and causes of concern.

Table 3. CORRESPONDENCE BETWEEN MODES OF RELEASE AND BASIC EVENTS

Events Leading to Gaseous Release Only

- differential settlement of tailings
- shrinkage (or thinning) of cap
- chemical attack on cap

Events Leading to Release to Groundwater

- seepage of tailings liquid to groundwater
- groundwater movement through tailings
- differential settlement of subsoil
- subsidence of subsoil and rock
- chemical attack on liner
- physical penetration of liner

Events Leading to Release on Surface

- static slope failure
- gullying
- floods
- earthquakes
- glaciation
- tornadoes and severe wind storms
- wind erosion

Events Leading to Gamma Ray Emission

- Any of the events leading to release of the tailings on the surface would be expected to lead to gamma ray radiation (and radon release)

Furthermore, the three alternatives under consideration are roughly equally likely to be adequate in preventing these two modes of release in the SR and roughly equally susceptible to release of comparable quantities of radon gas and gamma ray emissions in the LR. For these reasons, it appears that careful consideration of these two release modes is not likely to be productive in evaluation of the three alternatives.

Relatively speaking, however, release of radioactive material to the groundwater and on the surface are the more important modes. Furthermore, there are relative differences in the susceptibility of each disposal alternative to these two release modes. Hence, focusing attention on the probabilities and likely consequences of the remaining two release modes will be productive in evaluation of the disposal alternatives. The following discussion, therefore, will focus on (1) releases to the groundwater, and (2) releases on the surface.

4.4 IDENTIFICATION OF SIGNIFICANT EVENTS

Although the set of basic events presented in Table 2 provides a comprehensive list of natural occurrences that should be considered when evaluating any tailings disposal plan, it is not necessary that they all be analyzed in detail for each alternative.

In Appendix A each of the possible basic events is examined in light of the laternatives being considered (Figure 1) and their physical setting (Figure 2). From what emerges, it is immediately clear that some of the basic events are irrelevant for the three alternatives under consideration,

either because their occurrence is highly unlikely and/or they would be inconsequential if they did occur. Consideration of such events is not likely to be fruitful in evaluating the alternatives.

Only a few events are worthy of detailed consideration, either because relatively speaking they are more likely to lead to dispersion of the tailings and/or because they have different probabilities of occurrence for different alternatives. By focusing attention on these events, one can evaluate each alternative and discriminate among them.

The following is a brief summary of the conclusions of Appendix A:

- Differential settlement of the tailings is not considered likely to lead to any release, considering the particular methods proposed for depositing and distributing the tailings in the impoundment. Furthermore, since the cap would be flexible and plastic, differential settlement would not be expected to cause cracks in the cap. Differential settlement of the tailings would most likely occur (or begin) in the SR or never. As already stated, if it were to occur in the SR, it would be detected during the post-operational phase of the facility and remedial actions would follow. In any case, the likelihood of occurrence would be similar for all three alternatives and the consequences comparatively minor. Therefore, consideration of this event does not help to differentiate the alternatives.

- Shrinkage of the clay layer of the cap is unlikely to lead to cracks that would release radon gas. Even if cracks were to develop, by assumption, they would be detected and remedied in the SR. Furthermore, the potential for cracking due to shrinkage would be roughly equal for all three disposal alternatives and the consequences of cracking would be roughly equal and equally insignificant for all three alternatives. Therefore, cracking of the cap does not provide a basis for comparing the alternatives.

- Chemical attack on the cap is not likely and would not lead to adverse consequences even if it were to occur.

- Some seepage through the bottom liner is likely to take place for all alternatives. It is unlikely that seepage would reach the water table in the case of the natural basin and the partially excavated pit alternatives, although it appears almost certain that it would reach the water table in the case of the excavated pit alternative.

- Differential settlement of the subsoil is unlikely primarily because there is little or no subsoil for any of the alternatives considered. Differential settlement of the embankment is possible, but would not be a cause for concern given the specifications of the impoundment dam and containment dike. Furthermore, if differential settlement of the embankment were to occur, it would be detected and remedied in the SR by assumption.

- Subsidence in the subsoil and rock beneath the dam and the impoundment area is unlikely. The phenomena which cause subsidence are ineffective or not present within the massive sandstone formations of the Shootering vicinity.

- Chemical attack on the clay liner is not likely to occur and would not increase permeability appreciably even if it were to occur. Laboratory tests indicate that chemical interaction between the tailings liquids and the clay liner may actually decrease the liner's permeability of the liner.

- Physical penetration of the liner is considered unlikely due to the thickness of the clay liner.

- Static slope failure is not likely to be a problem. Since the impoundment dam would be raised in stages, any tendencies for such failure should be evident during the operation of the facility and would be appropriately corrected.

- Gullying is a concern, particularly in the case of the natural basin with impoundment dam, because of the relatively large exposed area of the dam. Gullying is viewed as a gradual event that would become progressively worse. Its rate of occurrence is analyzed further in Section 5.0.

- Floods are not expected to be common or of appreciable magnitude because of the low rainfall rate and relatively small watersheds involved.

- Earthquakes are not a major concern, because earthquakes severe enough to cause damage to any of the disposal alternatives are unlikely in the region.

- While there is a certain finite probability of glaciation near this area, it is not considered a major cause for concern.

- Tornadoes and severe wind storms are not considered likely at the site, nor are they considered as consequential for the alternatives being considered.

- Geomorphic features related to wind erosion are not present in the general site area. In addition, all three disposal sites are protected from direct exposure to the wind. It is unlikely that any release would occur due to wind erosion.

Table 4 summarizes these conclusions. From Table 4 it may be seen that for the particular sites and alternatives considered in this report, the following basic events may be consequential and must be studied in more detail:

- seepage of tailings liquid through the liner

- groundwater movement through tailings

- gullying

The other basic events are either much less likely to occur than those listed above, or their consequences are much less important than those of the three events above. In addition, many of the basic events are equally likely for all three alternatives and do not provide a good basis for differentiating the alternatives.

Table 4: SUMMARY OF THE LIKELIHOOD OF BASIC EVENTS LEADING TO RELEASE OF TAILINGS

Basic Events	Natural Basin with Impoundment Dam		Fully Excavated Pit		Combination Excavated Pit amd Containment Dikes	
	SR	LR	SR	LR	SR	LR
1-Differential Settlement of Tailings	*		*		*	
2-Shrinkage of the Cap	*		*		*	
3-Chemical Attack on Cap	*		*		*	
4-Seepage of Tailings Liquid to Groundwater	*		SL	SL	*	
5-Groundwater Movement through Tailings	*		SL	SL	*	
6-Differential Settlement of Subsoil and Subsidence	*		*		*	
7-Chemical Attack on Liner	*		*		*	
8-Physical Penetration of Liner	*		*		*	
9-Static Slope Failure	*		see Note A		*	
10-Gullying		SL		*		SL
11-Floods	*	*	*	*	*	*
12-Earthquakes	*	*	*	*	*	*
13-Glaciation		*		*		*
14-Tornadoes and Severe Wind Storms		*		*		*
15-Wind Erosion		*		*		*

Legend:

SR and LR represent short-run and long-run time frames. (See section 4.2.)

*indicates that the event is very unlikely to occur.

SL indicates that the event is Sufficiently Likely to occur, and that further analysis is warranted.

☐ indicates that the particular event is not relevant for the time frame under consideration.

Note A: Since the fully excavated pit does not have an embankment, this event is not applicable.

5.0

ANALYSIS OF THE ALTERNATIVES

Having identified the basic events that are likely to be of prime concern for each of the three alternatives, we now turn our attention to a discussion of the likelihood that each event will occur, the magnitude and types of releases that would be expected to occur, and the possible timing of the releases.

Once again, the short-run (SR), long-run (LR) distinction is necessary because some basic events are of a SR nature and could lead to the given failure modes only in the SR. With appropriate design and operation, most of these basic events can be prevented. If they should occur, they could be detected in their early stages and remedial measures carried out expeditiously. Furthermore, the question of when a particular SR event happens is not as important as whether it would occur.

In the LR, however, the situation is different. Some events are almost certain to happen at some future time; the important concern is to estimate when they might occur. The element of time is significant because the consequences of given events leading to release of radionuclides generally are dependent on time. It is the timing that is difficult to assess, because the state of the art does not permit

accurate forecasting for many of the events within the time frames under consideration.

Following is a discussion of what is considered likely to happen to each of the three alternatives in the SR and LR. The SR discussion is brief, because the potential problems are considered self-evident and, for the most part, of little or no consequence. Keeping in mind the basic limitations of long-term forecasting, a "most credible" scenario is developed for each alternative in the LR, and reasonable variations of the basic scenario are discussed. An attempt has been made to establish the minimum reasonable time before given events which would lead to given release modes are likely to occur. Magnitudes and probable consequences of different release modes are discussed in conjunction with each postulated mode of failure.

5.1 ALTERNATIVE 1: NATURAL BASIN WITH IMPOUNDMENT DAM

5.1.1 <u>SR Time Frame</u>

It is expected that nearly all the free water in the tailings would be removed by evaporation and drainage (Woodward-Clyde Consultants, 1978b, pp. 1-14 and 1-15). Some liquid might seep through the bottom liner or through the dam, but the dissolved radionuclides that escape would most likely precipitate or be adsorbed in the immediate proximity of the liner and would not be carried away with the seepage water. Since the groundwater level is about 100 feet below the bottom of the tailings at their

lowest point (WCC, 1978b, p. 1-33), the possibility of groundwater contamination is remote.

The tailings are expected to consolidate as successive layers are deposited in the impoundment and it is expected that cementation will begin (Appendix B). The chemistry of the tailings indicates that this process would most likely begin during the operational phase of the project. The tailings are expected to reach a state of chemical/physical equilibrium within a few decades after abandonment; at that point the bulk of the tailings would have turned into a solid, stable mass cemented by gypsum.

The impoundment dam and tailings cap are expected to function properly in the SR. All normal runoff from the basin and the suspended sediments are expected to be retained on the tailings cap. The runoff water would tend to keep the cap moist and reduce the potential for release of radon to the atmosphere. Accumulating sediments should increase the thickness of the cap and further impede gamma ray emission. In short, the natural basin with impoundment dam alternative is expected to function satisfactorily in the SR.

5.1.2 LR Time Frame

Normal fluctuations in the groundwater level are not likely to reach the tailings, nor is groundwater movement through the tailings expected. Furthermore, rainfall on the cap would most likely evaporate and would not provide a vehicle for movement of radionuclides through the bottom liner. The only conceivable way the tailings are likely to

become a potential source of radioactive release is if they should become exposed at some future time. As was concluded in Section 4, gradual water erosion is the event most likely to lead to exposure of the tailings over the long term. To analyze the long-term effects of water erosion, the following "most credible" scenario is presented.

Initially, sediments carried by water would accumulate on the tailings cap. The rate of sedimentation would depend on a number of parameters, including the average annual rainfall, runoff coefficient, watershed area, transport capacity of water, and the erodibility of potential sediment source material. Based on reasonable assumptions,* sediments may accumulate at the average rate of roughly 0.02 foot per year. At such a rate, a few hundred years would be required to fill the 4 feet of freeboard between the top of the cap and the discharge level in the spillway (WCC, 1978b, Figure 7). From that time on, much of the runoff water and contained sediments would be discharged through the two spillway provided. As long as the spillways function properly,** no appreciable amount of additional sedimentation would

*Eight inches average annual rainfall, 0.2 average runoff coefficient, 170 acres drainage area, and 1 percent (by weight) average sediment transport capacity by running water.

**There is a very small probability that the spillways would not function as planned, for example, because they were somehow obstructed. If this were to happen, sediments might continue to accumulate behind the dam and ultimately fill the reservoir. In this case, occasional heavy storms might overtop the crest of the dam. The probability that both spillways would become plugged over a long period of time is considered small. Even if the spillways were obstructed, much of the runoff and sediments would be discharged to the Lost Spring Wash (Figure 2) and would not accumulate behind the dam.

be expected and roughly 7 feet of freeboard would remain between the top of the sediments and the crest of the dam (Figure 4). Thus, as long as the crest of the dam remains intact, runoff would be expected over the top of the dam. Consequently, the major erosive force would be that of water falling on the crest and the downstream face of the dam.

Looking at the situation realistically, it is clear that water erosion of the face of the dam, if it occurs at all, would proceed at an extremely slow rate. An examination of the geology of the site confirms this statement. Most important, the effective watershed area - namely, the crest and outside face of the dam - has only about 3 acres of surface area. This, coupled with the low rainfall in the area (6 to 8 inches annually), suggsts that the volume of water involved in any given storm would be small. Furthermore, the exposed face of the dam would be covered with at least 5 feet of cobbles and gravel (WCC, 1978b, Figure 6), and would be resistant to erosion. Even though long-term forecasting is difficult and imprecise, it is probably safe to state that the armor is likely to protect the dam from erosion for many thousands of years.

Eventually, however, erosion will begin on the face of the dam. Thus, the important question is how long the dam can withstand these erosive forces, and contain the tailings. To answer this question, it is necessary to establish the most credible mode of failure and estimate the length of time required to reach the given mode of failure.

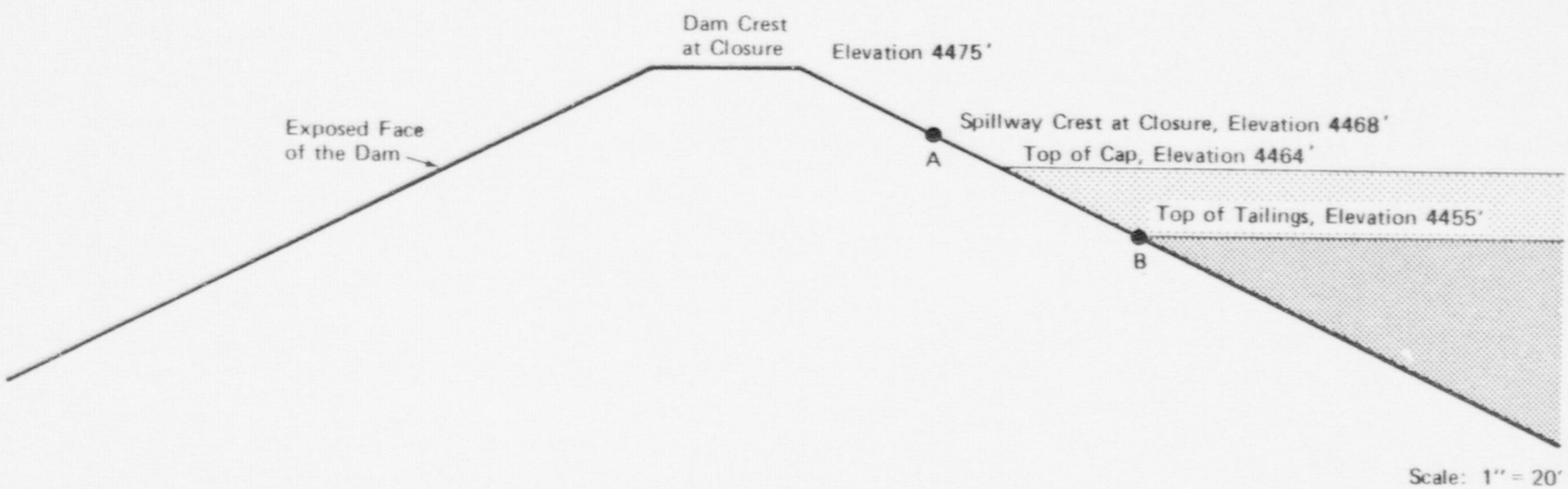


Figure 4. RELATIVE ELEVATIONS OF TAILINGS, CAP, SPILLWAYS AND DAM CREST AT CLOSURE (elevations shown based on assumed quantity of ore to be processed)

If gradual water erosion is to expose the tailings, the following sequence of events must take place:

Elimination of the Armor. Time must be allowed for the armor on the face of the dam to be effectively eroded, weathered, and/or displaced, because gullying (or any other form of erosion) will not commence until the armor is removed. It seems plausible that this layer will protect the dam for many thousands of years. An examination of aerial photographs from this area shows no sign of rapid gully erosion. All other indications confirm that elimination of the armor will be an extremely slow process.

Elimination of the Crest of the Dam. After the armor has been removed or penetrated, water sheet erosion should inevitably lead to gullying. Localized gullying could be expected to begin somewhere on the face of the dam, gradually cutting deep channels into it. Ultimately, one gully would cut a channel through the face and crest of the dam to the level of the spillways (point A in Figure 4). To estimate the length of time required for this event to take place, a simple model of gully formation and erosion was developed to provide guidance about the reasonable rate of erosion. This model is described in Appendix C.

Briefly, the model assumes that the gully would start on the surface of the dam, running from the toe to the crest along a straight line. As the gully progresses, it gradually cuts downward through

the crest of the dam. It is assumed that the straight line formed by the bottom of the gully is fixed at the toe and rotates downward through the dam.* The wedge-shaped channel cut by the gully will deepen, widen, and its bottom slope will become flatter with the passage of time.** Thus, with the geometry of the gully and the volume of the wedge known, one can describe the location of the bottom of the gully as a function of time. The volume of runoff water can be estimated using 8 inches of average annual rainfall and a 0.20 runoff coefficient. The rainfall collection area is assumed to be equal to the exposed surface area of the gully (which is known, given the geometry of the gully). It is assumed that runoff would carry on the average a sediment load equal to approximately 1 percent of the weight of the water falling in the gully.

The above assumptions lead to a differential equation which describes the progress of the gully as a function of time. The model indicates that the gully can be expected to cut down through the face of the dam at a rate of roughly one foot per thousand years. Accordingly, it would take on the order of a few thousand years to reach the level of the spillways (point A in Figure 4). The assumptions and the exact results of the above model are not as important as the fact that any analysis which makes similar assumptions about the collection area for

---

* This is a conservative assumption because deposition of the material at the toe of the dam probably would cause the toe of the slope to move away from the core as erosion progresses.

**Its bottom slope would change from the initial 1:2 slope to 1:8 slope by the time the gully contacts the tailings (point B in Figure 4).

rainfall and the sediment-carrying capacity of water will lead to results that are of the same order of magnitude as are obtained here.

<u>Exposure of the Tailings</u>. Once a gully has cut through the crest of the dam to the level of the spillways, water erosion would proceed at an accelerated rate, since all runoff from the watershed would drain through the cut channel rather than the spillways. But the tailings would not be exposed until the critical gully penetrates the sediments accumulated on the cap and the cap itself. Making appropriate assumptions* about the likely volume of water and its erosive capacity, one can estimate the length of time necessary for the gully to proceed from the spillway level to the point at which the tailings become exposed (point B in Figure 4). The analysis indicated that this process will take on the order of a few centuries.

Given that with the passage of time the tailings will eventually become exposed, it is important to ask how fast they would be dispersed and what the likely consequences of such dispersal would be.

As discussed in Appendix B, the chemistry of the tailings will be such that they would most likely be joined together to form what would be essentially a mass of sandstone cemented by a gypsum binder. Consequently, when and if the critical gully reaches the tailings, its rate of erosion will be exceedingly slow, particularly since the bottom of the gully must have a slope flatter than 1:10 by the time it

*In this case the volume of the runoff passing through the gully is assumed to be equal to the runoff from the entire watershed. Other assumptions are similar to those already stated.

encounters the tailings. In this case, the tailings would be released at rates so slow as to to be inconsequential in either absolute or relative terms.

The impact of release of tailings at such a slow rate will be minimal at the site and negligible within a relatively short distance from it. When the tailings reached Shootering Creek, they would be diluted by a factor of 0.01:1. The corresponding number when the tailings reached Hansen Creek would be 0.0025:1. These figures were obtained by assuming that all of the sediments washing out of the impoundment would consist of tailings; this implies that the tailings are not cemented together. The ratio of tailings to sediments in the lower reaches of Shootering Creek can be approximated by taking the ratio of the watershed area above the impoundment (roughly 220 acres, including the impoundment area itself) to the watershed area for Shootering Creek (roughly 32 square miles, or 20,480 acres). Similarly, the dilution rate in the Hansen Creek watershed area (roughly 135 square miles, or 86,400 acres) can be estimated. With such high dilution factors and considering the fact that the tailings themselves are little more than crushed natural rock with most of its uranium content removed, the impact of an eventual release would be negligibly small.

Two additional factors would further reduce the impact of any eventual release. First, as shown in Figure 3, the total level of radioactivity of the tailings would decrease exponentially over time. Hence, if the tailings were contained for several thousand years, their

radioactive potency would likely be reduced substantially. In fact, as already discussed in Section 4.2, if the tailings are contained for 15,000 years, their level of radioactivity would be reduced to that of the "permanent" base level radiation. Given the adequate design considerations provided, it would not be unlikely that the impoundment dam would contain the tailings for a 15,000-year period.

If the tailings are assumed to be uncemented (contrary to what is expected), an average erosion rate of roughly 200 cubic yards of tailings per year may be expected over a period of a couple of thousand years.*

Second, relatively speaking, the tailings would not be much more radioactive at the time they are deposited in the impoundment than are many of the cliffs and rocks that are found in the immediate vicinity of the natural basin. The fact that these rocks are and have been exposed and subject to gradual erosion for thousands of years indicates that once the radium concentrated in the tailings had decayed, the tailings would not have the potential to degrade the environment even if they did become exposed after many thousands of years. Viewed in relative terms, it appears that the natural basin alternative is more than adequate, given the present level of radioactive sandstones and shales exposed in the area.

---

*This approximate rate was obtained from the above analysis.

The following summary statements can be made with regard to the natural basin alternative:

- The proposed alternative can be expected to function satisfactorily in the SR.

- It is not unreasonable to expect the impoundment dam to remain intact and to contain the tailings for many thousands of years.

- The most credible LR failure scenario appears to be gradual surface erosion of the impoundment dam, ultimately leading to exposure of the tailings and subsequent dispersion by water.

- While the current state of the art does not permit a percise analysis of the probability of exposure of tailings through time, it can be seen that the probability of such an event occurring during the first few thousand years is negligibly small.

- In the event that failure and subsequent release were to occur at some future time, it would be gradual and its effects would, in all likelihood, be minimal. Three factors support this conclusion. First, as the above analysis indicates, the rate of release of the tailings, given the most credible mode of failure, would be slow, since the tailings would most likely be cemented long before failure occurs. Furthermore, by the time the tailings reach Shootering and Hansen Creeks, they would be greatly diluted.

  Second, since the tailings are expected to be contained for many thousands of years, their radioactive potency will be diminished by the time they are released. Consequently even if the release were delayed for only a few thousand years, the radioactivity of the material released would be substantially reduced.

  Third, as compared with the background levels of radiation in the immediate area, the gradual release of the tailings at some distant future time is not expected to degrade the environment. Consequently, the failure of the dam is not likely to be a major source of concern in either absolute or relative terms.

5.2 ALTERNATIVE 2: FULLY EXCAVATED PIT

5.2.1 SR Time Frame

Since the bottom of the tailings would be at or below the groundwater level,* seepage of tailings liquids into the groundwater should be anticipated. Depending on the hydrostatic head in the tailings, the seepage rate would vary over a wide range. Furthermore, with the passsage of time, the groundwater gradient around the pit would reestablish at its preconstruction level and would be likely to pass through the lower levels of the tailings. Hence, groundwater movement through the tailings might dissolve and carry radionuclides out of the impoundment. This process would most likely continue in the LR. Its probable consequences will be discussed below.

Even though the upper layers of the tailings would begin to consolidate, solidify, and cement, as described in Appendix B, the bottom portions of the pit might remain in a semisaturated state indefinitely. Firm cementation is less likely to occur under these circumstances than in the better drained portions. Otherwise, the fully excavated pit is expected to function satisfactorily in the SR.

5.2.2 LR Time Frame

It is likely that in the LR there would be a net outflow of dissolved radionuclides from the pit into the groundwater. This might occur either because of continued seepage and/or because future fluctuations

*Based on some preliminary studies, it is estimated that groundwater level would be roughly 5 feet above the bottom of the excavated pit.

in the water table might cause groundwater movement through the tailings. Three factors will, however, most likely combine to retard the rate of migration and reduce the effect of radionuclides leaving the impoundment.

The most important factor is the fact that groundwater velocities in the vicinity of the excavated pit are very slow.* The second factor is that radionuclides leaving the tailings would not move at the same rate as the water, but at rates that are many orders of magnitude slower (WCC, 1978b, pp. 1-27 to 1-30). Third, radionuclides not only move at extremely slow rates but, given the chemistry of the material likely to be found around the pit, react with other mineral components and groundwater and precipitate in the form of fairly stable compounds within a short distance from the tailings pit.** All these factors contribute to retard the migration rate and reduce the concentration of the dissolved radionuclides in the water. For example, it has been estimated that in materials similar to what could be expected near the pit, the 10 percent concentration contour for radium (which is more mobile than either thorium or uranium) will be formed at roughly 10 centimeters around the perimeter of the pond after a period of 10 years (Dames and Moore, 1978). This assumes a water velocity of $1x10^{-5}$

*Given a permeability of $2.6x10^{-5}$ cm/sec and an estimated 2.5 percent groundwater gradient, water velocity is estimated to be $6.6x10^{-7}$ cm/sec (i.e., roughly 2/3 foot per year).

**In fact, a large portion of radionuclides would probably precipitate within the clay liner itself.

cm/sec, which is considerably faster than would be the case at the Shootering Canyon site.

Thus, assuming that there are no continuous fractures in the excavated sandstone, the concentration of radionuclides in the groundwater should be near baseline levels within a short distance from the pit. In absolute terms the concentration of radionuclides in the groundwater would be nearly impossible to detect a short distance from the pit.

Therefore, even though seepage of radionuclides to the groundwater is virtually certain to occur, its effects would remain localized (i.e., limited to a small area in the vicinity of the pit). Hence, groundwater contamination would be a serious concern only if someone were to dig a well near the pit and draw water from the immediate proximity of the pit's bottom, or if a direct pathway (such as a fracture) were to run from the pit to some point on the ground surface or to a spring. The probability of either event is small. Thus groundwater contamination, in the sense that it would harm some living organism some distance from the pit, is seen as only a remote possibility.

As already pointed out, portions of the tailings might remain in a semisaturated state. Under these circumstances, complete cementation of the tailings might not occur, even in the LR. Thus, a portion of the tailings could remain in a state in which they could be more easily transported and dispersed by water than tailings more fully consolidated. There are several existing gullies and drainage channels in the sandstone near the site of the proposed excavated pit. The mere fact that

these gullies have formed over geologic time is an indication that the fully excavated pit is not indestructible in the LR* and gradual erosion may expose and disperse the tailings mass at some future time.** Such a process would, however, be extremely slow and is likely to take many thousand years to reach the tailings.

Summarizing the preceding discussion, seepage of tailings liquids and groun‹ ater movement through the tailings could be expected to continue for some time. This suggests that a potential for groundwater contamination would be present. Realistically, however, groundwater degradation would most likely be limited to a short distance around the pit, and its effect would reach negligible levels within a few hundred feet from the pit. Hence, unless some future population were to draw water from the immediate proximity of the pit,*** localized groundwater contamination does not appear to be a reasonable source of concern.

Gradual surface erosion ultimately could lead to partial e::posure of the tailings. However, the fully excavated pit alternative is expected to be less susceptible to such processes than is the natural impoundment

---

*In fact, the sandstone surrounding the pit is relatively soft and its rate of erosion may be comparable to that of the armored face cf the embankment dam already discussed.

**It is expected that the existing gullies--Lost Springs Wash on the north and an unnamed gully on the east--would be the causative agents for such exposure.

***Several factors, including the remoteness of the site from present (and anticipated) population centers and depth to groundwater near the site, indicates that the probability of such an event is remote.

alternative. Furthermore, if a release were to occur as a result of surface erosion, the magnitude and rate of release would be smaller for this alternative than for the natural basin alternative because of the smaller watershed area associated with the pit.* Needless to say, processes such as those described in Section 5.1.2** would be active, reducing the effects of any release and confining the impact, if any, to a small area.

In short, the following statements can be made about the fully excavated pit:

- The potential for groundwater contamination may exist both in the SR and LR. The extent of groundwater contamination would most likely be confined to a short distance around the bottom of the pit. The probability of detrimental consequences in the SR or LR are small.
- Gradual surface erosion might expose the tailings after the passage of many thousands of years, but the effects of such a release would be expected to be insignificant in either absolute or relative terms.

*If, however, Lost Spring Wash were to penetrate the pit, the erosion rate could conceivably be greater (rather than smaller) because Lost Spring Wash has several square miles of drainage area.

**I.e., slow rate of release (given that release occurs), reduced radioactive potency (due to decay), and small amount of radioactivity involved relative to the background level of radioactive rocks in the area.

5.3 ALTERNATIVE 3: COMBINATION EXCAVATED PIT AND CONTAINMENT DIKE

5.3.1 SR Time Frame

Since the bottom of the partially excavated pit is roughly 90 feet higher than the bottom of the fully excavated pit (WCC, 1978a, p. 33) the tailings liquids would be unlikely to reach the groundwater.* Should a fraction of these liquids reach the groundwater, relatively small quantities would be involved and the impact, if any, would be localized (see discussion in Section 5.2.2). Overall, this alternative should function more than adequately in the SR.

5.3.2 LR Time Frame

Gradual surface erosion would be the only other source of concern, particularly since the pit would be surrounded by a containment dike on nearly all of its perimeter.** This dike would be susceptible to gradual gully erosion due to rainfall. The length of time required to expose the tailings by erosion would be dependent on the surface erodibility of the dike and the effective watershed area. Since the exposed surface of the dike would be covered by an armor similar to that of the natural basin alternative, and the effective watershed area (i.e., the exposed face of

*It is estimated that the groundwater level would be approximately 85 feet below the bottom of the partially excavated pit.

**The dike would vary in height from about 0 to 90 feet, with an average height of 60 feet (WCC, 1978 a, p.33).

the gully) would be roughly comparable,* the probability of gully formation and its rate of progress for this alternative would be about the same as for the natural basin alternative.

Given that a failure would eventually occur, however, the magnitude of release of tailings would probably be smaller and the rate of release slower than the corresponding values for the natural basin with impoundment dam alternative. Cementation of the tailings, which would be nearly certain to occur, would act to slow the erosion rate. Furthermore, the processes described in detail in Section 5.1.2 would be present and combine to reduce the impact of any possible release at some future time to a negligibly small level.

Overall, the following statements can be made in regard to this alternative:

- Groundwater contamination would be unlikely to occur. Even if some seepage were to occur, its magnitude would be smaller than for the fully excavated pit alternative; and the impact, if any, would be more localized.

- Release of tailings from this alternative due to gully erosion would have roughly the same likelihood as for the natural basin alternative. However, if a release were to occur it would be at a slower rate due to the smaller watershed area involved.

*The freeboard distance from the top of the cap to the crest of the dike is about the same also.

6.0

EVALUATION AND CONCLUSIONS

It is apparent from the previous sections that the evaluation of tailings disposal alternatives must account for the uncertainties about whether certain releases might occur, the timing of the releases if they do occur, and the amounts of radioactive materials that might be released. The analysis so far has identified the major potential release mechanisms and placed some approximate bounds on them. From this analysis a pattern has emerged that can provide the basis for the evaluation.

Up to this point the analysis has focused solely on issues related to safety. This is considered appropriate, since the primary concern with respect to tailings disposal must be to provide adequate protection to the public and to the environment. Consequently, the first part of this section will be an evaluation of the safety of each alternative.

After the safety of the alternatives has been evaluated, the broader question of the relative desirability of the alternatives remains. In making such an evaluation, additional criteria should be considered. Cost effectiveness may be a major consideration because there may be substantial differences in cost among alternatives, while the benefits are very similar. Other factors, such as aesthetics and commitment

of land resources, may also be considered; however, all of the alternatives have similar impacts (which are not very significant to begin with). Consequently, such criteria do not seem helpful in making a comparative evaluation. The second part of this section makes a comparative evaluation of the three alternatives taking cost effectiveness into account.

6.1 EVALUATION OF ALTERNATIVES BASED ON SAFETY CONSIDERATIONS

The safety of the alternatives is evaluated with respect to the likelihood of release of radon gas, migration of radionuclides to the groundwater, dispersion of materials on the ground surface, gamma ray radiation, and the magnitude of the potential release, should one occur.

Of the four classes of releases, the release of radon gas and gamma ray radiation are not of major importance to the evaluation process since each disposal alternative would require the tailings to be covered with a similar clay cap, designed to meet the NRC's objectives with respect to both radon retention and gamma ray attenuation. The following evaluations, therefore, focus on seepage of radionuclides to the groundwater and dispersal of tailings.

6.1.1 Alternative 1: Natural Basin with Impoundment Dam

There is little likelihood of contamination of the groundwater from this alternative due to the substantial separation between the tailings and the water table. Dispersion of tailings by water erosion is likely at some future time. Two factors will, however, act to mitigate

the consequences of this eventuality. First, it is unlikely that the tailings would become exposed until many thousand years have passed. By that time, the radioactivity of the tailings would be greatly reduced. If the exposure were delayed by 15,000 years, the level of radioactivity would be essentially equal to background levels in the vicinity.

The second factor is that the tailings probably would be cemented into a sandstone mass that would be quite resistant to erosion. As a result, even if tailings exposure by erosion were to occur, there would not be any significant dispersal of the tailings. If it should happen that the tailings did not cement as expected, then the maximum rate of dispersion of the tailings would be on the order of a few hundred cubic yards per year. This material would be mixed with and diluted by the sediments carried by both Shootering and Hansen creeks, making such a release relatively innocuous.

It is concluded that tailings disposal in the proposed natural basin with impoundment dam is acceptable from the viewpoint of safety considerations. This conclusion is based on the observation that groundwater contamination is not expected to occur. Furthermore, tailings dispersal by water erosion is unlikely to occur within the next few thousand years, and will be slow and relatively inconsequential if it does occur after that.

6.1.2 Alternative 2: Fully Excavated Pit

This alternative would be safe from erosion and dispersal of the tailings for many thousands of years. It is expected, however, that there would be some contamination of the groundwater. It is unlikely that this contamination would result in exposure to man. The radionuclides in the seepage water would precipitate out of solution in the rock surrounding the pit, and their migration from the immediate vicinity of the pit would be exceedingly slow.

This disposal alternative is also viewed as being acceptably safe since it would not be particularly susceptible to surface dispersal within the time frame of concern. Furthermore, any contamination of the groundwater (which would be expected to occur) should be confined to the immediate vicinity of the pit at considerable depth, making it unlikely that any significant exposure to the public would occur.

6.1.3 Alternative 3: Combination Excavated Pit and Containment Dike

The safety of this alternative would be similar to the safety of the natural basin alternative. There is little likelihood that there would be contamination of the groundwater, because of the depth to the water table at the site. As is the case with the natural basin alternative, the most significant source of long-term concern would be the possibility of dispersion of the tailings by gradual water erosion. The likelihood of this event would be roughly equal to that for the natural basin alternative and probably a little greater than that for the fully excavated

pit alternative. If the tailings cement together as expected, the rate of release due to erosion would be slow. If, however, adequate cementation did not occur, then it is expected that the release rate would be less than that of the natural basin alternative.

Thus, this disposal alternative is also considered acceptably safe. The likelihood that any release would occur is quite similar to that for the natural basin alternative, but the magnitude and rate of the releases should be smaller.

6.2 EVALUATION OF THE ALTERNATIVES BASED ON SAFETY AND COST-EFFECTIVENESS CONSIDERATIONS

From the preceding discussion it is concluded that no one of the alternatives would be obviously the best from a safety standpoint. With the natural basin and the partially excavated pit alternatives, there would be the possibility of low-level surface dispersal a few to several thousand years in the future, while with the fully excavated pit alternative, there would be a near certainty of a localized contamination of the water table.

Choosing among these alternatives requires value judgments, and weighing of the consequences of groundwater contamination against surface dispersal, considering that one consequence would be likely to occur relatively soon, while the other consequence would occur in the far future. Reasonable persons could disagree as to which alternative offers greater overall safety.

We have not attempted to make such a choice based solely on safety consideration, partly because of the value judgments required and partly because the analysis presented here demonstrates that the consequences arising from releases with any of the alternatives would be small. Hence, any one of the three alternatives would be acceptable if safety were the only criterion.

Other criteria are, however, also relevant to an evaluation of the alternatives. A major criterion among these is cost effectiveness. As can be seen from Table 5, the natural basin with impoundment dam alternative is roughly $20 million less costly than the fully excavated pit and about $17 million less costly than the combination excavated pit and containment dike alternative. Since the cost considerations favor the natural basin alternative, an analysis may be made by comparing the incremental costs of the other two alternatives with the incremental benefits they offer.

When the natural basin alternative is compared with the fully excavated pit, it is not clear that there would be any significant improvement in safety. In fact, it may be argued that if localized groundwater contamination in the near future were weighed more heavily than low-level surface dispersion in the far future, then the fully excavated pit would result in a net reduction in safety. This would be a value judgment, but it does appear doubtful that the additional cost of the fully excavated pit could be justified on the basis of increased safety.

Table 5. ESTIMATED CAPITAL COSTS TO DEVELOP ALTERNATIVE TAILINGS DISPOSAL SYSTEMS

Alternative	Cost
1. Natural basin with impoundment dam	$11,100,000
2. Fully excavated pit	$31,400,000
3. Combination excavated pit and containment dike	$27,900,000

Source: WCC, 1978a, Table 3 (Estimates by Mountain States Engineers, Tucson, Arizona).

When the natural basin alternative is compared with the combination excavated pit and containment dike alternative, a case can be made that the partially excavated pit is likely to be at least as safe as the natural basin alternative. In the event that the tailings do not cement as expected, the releases from the partially excavated pit would be expected to be less than from the natural impoundment (assuming that releases do occur). Therefore, the combination excavated pit and containment dike may result in a marginal gain in safety over the natural basin.

This possible marginal gain in safety must be compared with the additional $17 million in costs. Whether the marginal gain in safety would justify the additional expenditure is a value judgment to which there is no unequivocal answer. Considering that the natural basin would be an acceptably safe disposal alternative, the net gain in safety obtained by reducing possible releases in the distant future would not be weighed heavily.

6.3 CONCLUSIONS

If safety is the only criterion used in evaluating the three disposal alternatives considered, no unequivocal conclusion can be drawn. This statement is based on the analyses of Section 5, which assert that all three tailings disposal alternatives are acceptably safe. When both safety and cost effectiveness are considered, it is concluded that the natural basin with impoundment dam alternative is preferable to the other alternatives.

APPENDIX A

EVALUATION OF LIKELIHOOD OF OCCURRENCE OF BASIC EVENTS

This appendix discusses the likelihood of each of the basic events identified in the body of this report. Relevant information available at this time is summarized for each event and is used to make a qualitative evaluation of likelihood.

Differential Settlement of the Tailings

Differential settlement of the tailings could be a concern if tailings were deposited in the impoundment in an uncontrolled manner. In that casse, the tailings would form zones of different size fractions, the coarser particles tending to collect on the sides of the impoundment near the points of discharge, and the finer particles and water tending to occupy the deeper zones. If this were permitted to occur, large differential settlements could take place within the tailings mass, because different zones would have different compressibilities and rates of drainage.

But according to the tailings management plan (Woodward-Clyde Consultants, 1978c), the controlled placement of tailings would produce a relatively homongeneous distribution of different size fractions throughout the impoundment. The result of the operation would be a continuous

buildup of thin, alternating layers of sand and slime solids. This procedure would minimize the differential settlement of tailings within the impoundment.

Estimates of differential settlement across the impoundment, made without considering the effects of dewatering of the slimes by evaporation and drainage, indicate that the settlement profile would have less curvature than the allowable curvature for brittle structural materials, e.g., sensitive floor finish (NAVFAC, 1971). The clay cap would be approximately 6 feet thick, and its plasticity and self-healing qualities would permit it to accommodate minor differential settlement without cracking.

Shrinkage of the Cap

In general, both the shrinkage potential and the swelling potential of soils depend on their plasticity classification; the more plastic a soil, the greater the potential for shrinkage and swelling. Shrinkage properties of soils are also affected by particle arrangement, initial water content, and confining pressure.

The construction material for the clay cap would be obtained from the borrow area "F" marked in Figure 5 of Woodward-Clyde Consultants (1978c). Figures C-42 and C-44 of that report present representative plasticity classification and grain size distribution data for this material.

With a plasticity index of 16 percent, the clay cap material is expected to exhibit a low potential for shrinkage, even if it were to

dry completely. In addition, design recommendations, such as control of the placement water content and provision of confining pressure by covering the clay layer with layers of sandy material, gravel, and cobbles, would further reduce the shrinkage potential of the cap. The covering armor also places the clay well below the depth of seasonal moisture variations, thereby rendering cracking of the cap due to shrinkage a remote possibility.

Chemical Attack on the Cap and Chemical Attack on the Liner

The clays from borrow area "F" to be used as liner and cap material were tested with simulated tailings liquid (Woodward-Clyde Consultants, 1978c). Treatment with that acidic liquid indicated a decrease of the hydraulic conductivity of the clay while leading to an increase in pH of the tailings liquid.

The clays proposed for the cap and liner probably are derived from sedimentary rocks which were deposited in a marine environment during the Cretaceous period. The effect of acids on such materials would be to extract the exchangeable cations. There is little reason to be concerned about chemical decomposition of the contained silicates by the acid. Research on clay minerals indicates that if the acid attack is prolonged and the acid replenished as it is consumed, the silicate framework may be attacked. According to Grim (1955), under such an environment the alumina octahedral layer and the silica tetrahedral layers are attacked successively. At least 75 percent to 80 percent of the total alumina must be removed from the clay minerals before the

clay structure is completely destroyed. There would, however, be a limited and progrssively diminishing supply of acid in the impoundment after the tailings are capped. During placement, the tailings acid would be neutralized by adding high-carbonate mine waste rock to the impoundment. Under such conditions, there would be little likelihood that the acid would significantly affect the properties of the clay.

Seepage of Tailings Liquid to Groundwater

Some tailings liquid is expected to seep through the clay liner for each of the alternatives. For the natural basin alternative, the amount of seepage under "worst case" conditions (no tailings drainage) was estimated to be on the order of 413 acre-feet over the planned 20-year life of the project (Woodward-Clyde Consultants, 1978b). The amount of seepage would be similar for the other two alternatives.

In the case of the natural basin alternative, the water table is about 100 feet below the low point of the impoundment. For this alternative, it is expected that little or no seepage would reach the groundwater (Woodward-Clyde Consultants, 1978b) due to the depth of the water table and the large volumes of unsaturated rock which would absorb the seepage. Seepage from the partially excavated pit alternative also would be unlikely to reach the water table for the same reasons. The bottom of the combination excavated pit and containment dike would be approxmately 85 feet above the water table (Woodward-Clyde Consultants, 1978b). However, in the case of the fully excavated pit, some seepage

would be expected to enter the groundwater, since it is estimated that the water table would be at, or even slightly above, the bottom of the pit.

Due to these considerations, it is clear that the question of seepage bears strongly on the relative and absolute desirability of the alternatives. Therefore, the magnitudes and potential consequences of seepage are considered more fully in the main body of the report.

Groundwater Movement Through the Tailings

If the tailings impoundment (or any part of it) were below the groundwater level, contamination of the aquifer by radionuclides would be possible due to groundwater movement through the tailings.

In the case of the fully excavated pit, the approximate location of the groundwater table would be near the bottom of the pit. It is possible that in the future the groundwater table would rise sufficiently to cause flow through the tailings. The consequences would be similar to the consequences of seepage of tailings liquid from the pit. This is discussed in further detail in the body of the report.

The other two alternatives would be beyond the range of conceivable groundwater fluctuations. Therefore, it is unlikely that there would be any movement of groundwater through the tailings for those two alternatives.

Differential Settlement of the Subsoil and Subsidence

In all cases, the clay liner would be laid directly on bedrock. Consequently, no differential settlement of the subsoil would occur. Nelson and Shepherd (1978) list a number of causes of subsidence of subsoils and rocks. None of the identified causes are applicable in the Shootering Canyon area. Significant lowering of the groundwter table and removal of oil or gas deposits are not foreseen to cause localized differential subsidence of the area. The rocky base of the impoundment consists of massive, cemented sandstone that is unlikely to contain significant joints, cracks, or subterranean voids. Therefore, subsidence is a remote possibility.

Chemical Attack on the Liner

This was discussed above under chemical attack on the cap.

Physical Penetraion of the Liner

The design liner would consist of a compacted clay soil installed over a shaped base and with proper control of moisture and compactive effort. The design thickness of the liner would vary from 2 feet to 20 feet. Under these circumstances, penetration of the liner by foundation protruberances or other objects would be unlikely.

Static Slope Failure

As used here, the term slope failure refers to the static failure of the embankment slopes in the short-run time frame. In principle,

such a failure would be induced by excessive shearing stresses in the embankment materials. Unless the slope was properly designed and constructed, it could be brought to failure in the short-run time frame (operational phase) as the tailings and tailings liquid levels rose. Stability of the slope during this phase would be critical, since the pore water pressures in the embankment material would tend to reduce the available resisting forces. By contrast, in the long run, the tailings pressures on the dam would be reduced due to drainage and consolidation, and the shearing resistance of the slope would increase due to dissipation of pore water pressures.

The impoundment dam would be designed with proper consideration of all forces to minimize the potential for slope failure. Also, short-run slope failure would not be a significant threat, since the dam would be continuously monitored, and remedial measures could be implemented promptly following any observed threat of a failure.

Gullying

In the cases of the natural basin alternative, and the combination pit with containment dike alternative, gullying was considered a process that could lead to dispersal of tailings. A discussion of this mechanism is presented in the body of the report.

In the case of the fully excavated pit, gullying and water erosion would be unlikely to lead to a release, since the tailings would be completely below the surface of the adjacent undisturbed rock and because the associated watershed area ia quite small.

Floods

Floods are caused by heavy rainfall occurring within a short time period. By contrast, erosion may progress without flooding. The two events are distinguished by the fact that in the case of the natural basin alternative, it is conceivable a flood could overtop the dam and accelerate the development of a gully through the dam into the tailings. For the other two alternatives, there is little tributary watershed and floods are essentially not relevant.

The natural basin alternative has been designed to store the runoff from a sequences of storms having 17.7 inches of total precipitation. This is equivalent to 1.4 times the probable maximum 6-hour precipitation, plus the 100-year 6-hour precipitation. The return period of such a storm may be approximated by exptrapolating from the return intervals for storms of smaller size. Using data for the project vicinity, such an extrapolation indicates a return interval several orders of magnitude greater than the long-term time frame considered appropriate for this analysis. Thus, it is unlikely that a flood would, by itself, cause a release to occur.

Earthquakes

The failure modes that could be associated with a severe earthquake in the area are cracking of the liner and failure of the embankment.

The facility site is located about 100 miles east of the nearest active fault system in the Rocky Mountain zone. Ryall et al. (1966)

established recurrence rates on the order of 0.002 shock per year per 1000 km^2 in the zone for magnitude 7 earthquakes. This means that the recurrence interval is on the order of 500,000 years for a magnitude 7 earthquake occurring at the site. For a magnitude 7 earthquake occurring 100 miles from the site, the maximum probable bedrock acceleration at the site would be less than was assumed for the project design. Based on this consideration, failures due to earthquakes are considered to have low probabilities for all three alternatives.

Glaciation

Glaciation refers to erosion caused by moving ice masses, with consequent modification of land forms.

The recorded geologic history of the entire Colorado Plateau area is one of progressive fluviatile erosion. Glacial and periglacial deposits occur only locally at higher elevations (Karlstorm, 1976). Considering the topographic features of the site and vicinity, and past geologic records of the area, the possibility of glacial activity at the site is remote. Local ice development and movement at higher elevations may have some impact on the regional surface hydrology. Although snowmelt runoff could produce mud flows in the area, these would be expected to flow down Lost Spring Wash north of the disposal areas considered and should not affect the tailings disposal sites.

Tornadoes and Severe Wind Storms

Tornadoes have been observed in the general region, but they occur infrequently. Based on the work of Markee et al. (undated), the prob-

ability of a tornado striking a given point in the vicinity of the facility site is estimated to be 0.000032. Accordingly, the recurrence interval of such an event at any point in the area is estimated to be 31,000 years.

The relatively short duration of tornadoes and the presence of the gravel and cobble armor on exposed surfaces make it unlikely that a tornado passing over the impoundment could cause any significant radioactive release. If the armor is not eroded by other mechanisms, tornados and severe wind storms could not cause significant damage (Nelson and Shepherd, 1978) even in the long-term time frame considered here.

Wind Erosion

In general, a significant amount of erosion is possible due to wind action over smooth, bare ground composed of loose and dry soil. Such conditions are not present at the Shootering Canyon site.

Applicable erosional processes in the project vicinity include the combined action of water and wind. According to Hunt (1953), the rate of surface degradation due to the combined effects of water and wind erosion is roughly 0.7 feet per thousand years throughout the Colorado River watershed area. Just how much of this degradation is attributable to wind erosion could not be determined.

Marked evidences of water erosion are present in the project vicinity in such features as abandoned drainage basins, pediment gravel

benches, etc., whereas geomorphic features attributed to wind erosion are generally absent. It could, therefore, be assumed that wind erosion processes are not significant in the project area. Further, all three alternatives would be located at sites which are generally protected from direct exposure to the wind.

REFERENCES TO APPENDIX A

Grim, R.E. 1955. Clay Mineralogy, 2nd ed. New York: McGraw Hill.

Hunt, C.B. 1953. Geology and Geography of the Henry Mountains Region, Utah. Geological Survey Professional Paper. 228.

Karlstorm, T.N.V. 1976. Quarternary and Upper Tertiary Time-Statigraphy of the Colorado Plateaus, Continuous Correlations, and Some Paleoclimatic Implications. In W.C. Mahoney, ed., Quarternary Statigraphy of North America, pp. 275-282.

Markee, E.H., Jr., Beckerly, J.G., and Sandus, K.E. Undated. Technical Basis for Regional Tornado Centers. WASH. 1300. Washington, D.C.: U.S. Atomic Energy Commission.

Department of the Naval Facilities Engineering Command. 1971. Design Manual: Soil Mechanics, Foundations and Earth Structures, DAVFAC DM-7. Washington, D.C.

Nelson, J.D., and Shepherd, T.A. Evaluation of Long-Term Stability of Uranium Mill Tailings Disposal Alternatives. Final Report, prepared for Argonne National Laboratories, April 1978.

Ryall, A., Slemmons, D.B., and Gedney, L.D. 1966. Seismicity, Tectonism, and Surface Faulting in the Western United States During Historic Time. Bulletin of the Seismological Society of America 56(5): 1105-1135.

Woodward-Clyde Consultants. 1977. Preliminary Geotechnical Engineering Report, Shootering Canyon Uranium Project, Utah. Prepared for Plateau Resources Limited, April 1977.

Woodward-Clyde Consultants. 1978a. Environmental Report, Shootering Canyon Uranium Project, Utah. Prepared for Plateau Resources Limited, May 1978.

Woodward-Clyde Consultants. 1978b. Responses, Nuclear Regulatory Commission Requests for Additional Information. July 237, 1978, Shootering Canyon Uranium Project Docket No. 40-8698. Prepared for Plateau Resources Limited, July 1978.

Woodward-Clyde Consultants. 1978c. Tailings Management Plan and Geotechnical Engineering Studies, Shootering Canyon Uranium Project, Utah. Prepared for Plateau Resources Limited, September 1978.

APPENDIX B

DESCRIPTION OF TAILINGS OVER TIME

This appendix briefly describes the physical and chemical condition of the tailings from the time they are deposited in the disposal facility. It is intended to provide information relative to conclusions and statements made in the body of the report. The first part of this appendix discusses the chemistry of the tailings over time. The second part discusses the radioactive decay that would take place in the tailings. The migration rate of the radionuclides after they leave the impoundment, which is of crucial significance to the present study, has been discussed in Woodward-Clyde Consultants (1978, pp. 1-27 to 1-30) and is not repeated here.

Chemistry of Tailings Over Time

A consideration of principal interest in the evaluation of the long-term stability of tailings from a uranium mill is the chemical characteristics of the tailings mass when deposited in the impoundment and the subsequent variation of those characteristics with time. From a practical point of view, the purpose of the milling has little to do with the important chemical reactions that take place during the milling and thereafter. That is to say that the presence of the

uranium (and its daughter products) plays no significant part in the chemical or physical nature of the tailings during milling, during transport to the tailings impoundment, or after deposition.

Basically, the milling process consists of physically breaking down sandstone to its composite grains and adding acid to dissolve and decompose the cementing material that holds the grains together. The bulk of the added acid is consumed in this process. The remaining acid is only that quantity needed to effect conditions necessary for phase exchange of the uranium. Other reactions, such as those brought about by the combined oxidant (chlorate and ferric iron), are relatively inconsequential to the physical and chemical state of the tailings mass inasmuch as only elements present in trace quantities are subject to oxidation by this method.

The chemistry of the tailings, therefore, is dominated by the resultant of the interaction of the original cementing material and the acid added during the milling process. It has been estimated that the sandstone ore is likely to contain by weight about 10 percent calcium carbonate or its equivalent. Thus it can be inferred that dolomite, magnesite, siderite, or various other carbonates, may possibly be present in trace amounts. Because of its ready reaction with acids, and its relative abundance, calcite ($CaCO_3$) is the ore component most apt to be attacked during the milling process. The sand grains themselves are essentially stable, although the very fine grains and clays may be subject to attack with the formation of silicic acid. Dolomite and siderite react

slowly with acid (cold) and are less likely to react in the mill than after deposition in the tailings impoundment.

The reaction of the sulfuric acid with the calcite, therefore, results in the formation of a solution that quickly becomes saturated with calcium ions, leading to precipitation of calcium sulfate during the milling process. This precipitation would continue (to some equilibrium point) in the deposited tailings. The continued presence of excess sulfate and of calcium ions would promote the growth of calcium sulfate crystals and, in the confines of the tailings mass, would tend to cement the mass. Similar reactions would occur with the less abundant components of the solution, in that crystal growth affords the ions a lower energy level than they would have in solution, in colloidal form, or in the form of finely divided precipitates.

Over the long term, the moisture content of the tailings mass would be expected to come into equilibrium with the environment. The acid content would be subject to continual reduction by reactions with the mass components, and with carbon dioxide contained in infiltrating air or water from the surroundings. The management plan proposes to accelerate the reduction of tailings acid content so that within a few days of deposition, the pH of the interstitial liquids would be considerably higher than upon deposition. The plan provides for neutralization of the tailings acid by addition of carbonates contained in mine waste rock. Also, the waste rock would be expected to promote drainage of the tailings slimes within the impoundment.

Crystalization of the cementing materials, produced by the reaction of the ore, would be accelerated to some degree by drying, but the presence of the sulfuric acid and certain salts added or produced during the chemical reactions would maintain a certain humidity level in the bulk mass even when exposed to the relatively arid atmosphere of southeastern Utah. This humidity maintenance would aid in the development of crystalline cementing material between the individual grains of the tailings. Best reactions would be expected on drained material, protected from excessive water loss to the atmosphere by burial.

Judging from field observations of soils in the project vicinity, calcium sulfate cystals form in large scale near the air/soil interface due to evaporation of water from infiltrating solutions. Once formed, the crystals are resistant to re-solution and, unless subjected to mechanical forces, are surprisingly stable even when deposited in stream beds.

The alternative plan that would place the tailings in contact with or near groundwater in an excavated pit would generally deter crystal formation within the lower part of the mass and, of course, subject the contained ions to leaching by the groundwater flow.

The time required for chemical equilibrium to be established within the tailings mass is probably on the order of decades. Use of boulders, cobbles, and gravel, derived from the mountains, for surface armor would promote such equilibrium. The armor would provide a source of calcium,

magnesium, and iron ions, which would result in an accumulation of carbonate (through reaction with the carbon dioxide in the air) that would act to seal the tailings surface. Also, the carbonate would continue the reduction of the acid content of the tailings mass. Thus, while the production of calcium sulfate crystals would occur over a relatively short period, the likely overall environmental response would be the formation of carbonate (i.e., calcite) crystals, which would be less soluble and more stable in the long term than the gypsum (calcium sulfate) crystals.

The result would be a progressive mineralogic stabilization of the tailings mass. The mass would become increasingly resistant to erosion, leaching, or penetration by groundwater or by surface seepage. Crystallization of calcium compounds would promote precipitation of other ions within the crystals formed. Since radium is one such ion, and it is closely related chemically to calcium, radium ions would be trapped within crystals of gypsum, anhydrite, or calcite (etc.). The process would be expected effectively to eliminate the potential for radium to leach from the tailings mass or, if tailings dispersal by erosion should take place, to prevent the ready release of radium to solution in the surface environment.

The conditions brought on by tailings crystallization, therefore, would not only act to stabilize the tailings mass chemically and physically but would also reduce the radioactive hazard of accidental release with time. Radium and its daughters, as well as uranium and thorium, would

progressively be removed from solution, or easy access to solution. Additional mechanisms most apparent in finely divided solids, such as ion exchange, also would act effectively to remove heavy elements from solutions and, in so doing, would help to promote their inclusion in crystals developing in the tailings interstices. Heavy radioactive elements are particularly subject to removal from solution at solid surfaces because of their high nuclear charge density and the related high polarizability of the atom. These effects would be enhanced as the water content of the tailings mass dropped, since water tends to screen these so-called "weak" forces.

Decay Rate of the Tailings

On an assumed basis of 0.10 percent U_3O_8 content in the ore processed and an equilibrium level of radium-226, over the 15-year life of the ore processing plant* some 1050 curies of radium would be discharged to the tailings impoundment. Approximately 10 percent of this quantity as discharged would be locked in some crystal form from which neither radium nor its daughters would escape. This quantity also represents the "permanent" radioactive base of the tailings, in that the bulk of the unrecoverable uranium also would be locked in these crystals. Consequently, 90 percent, or about 950 curies, of radium-226 would be mobile within the tailings at the end of the operations phase of the facility. This radium probably would

*Presently identified ore reserves will support plant operations for slightly more than 10 years. It has been assumed that additional ores will be located to supply the plant for at least 15 years, and plant facilities have been planned on that basis. The tailings disposal facility has been planned to contain tailings from 20 years of plant operations in case ore reserves exceed present expectations.

be in a form sufficiently free to release radon to the surrounding water or air. Also, the radium would be subject to leaching phenomena, although limited by its solubility. As placed, the tailings would be in the worst-case situation. After placement, the situation would improve because of the precipitation and crystallization phenomena discussed above. This worst-case assumption, however, permits a time frame to be established for which the integrity of the impoundment-containment is important.

If all of the 950 curies (9.5×10^{14} picocuries) of radium were fully disseminated in the 2600 acre-feet of disposed material (2600 acre-feet $\times$ 1233 m^3/acre-foot $\times$ 1000 $1/m^3$ = 3.21×10^9 liters), the conce[illegible]n of Ra-226 would be 2.96×10^5 pCi/liter. Similarly, the [illegible]vel due to radium in equilibrium with uranium locked in crystals (see above) would be

$$105 \times 10^{12} \text{ pCi} \div 3.21 \times 10^9 \text{ liters} = 3.27 \times 10^4 \text{ pCi/liter}$$

The point in time at which the "free" radium content would be relatively insignificant compared with the "permanent" base level (taken as 1 percent of the base level) would be found as follows.

$$A = Aoe^{-\lambda t}$$

where, $Ao = 2.96 \times 10^5 \text{pCi/1}$

$A = 3.27 \times 10^2 \text{pCi/1}$

$$t = \frac{\ln \frac{Ao}{A}}{\lambda} = \frac{\ln \left(\frac{2.96 \times 10^5}{3.27 \times 10^2}\right)}{1.37 \times 10^{-11}} = 4.97 \times 10^{11} \text{secs.}$$

$t \approx 15.7 \times 10^3$ years.

As discussed in the body of the report, 15,000 years is the approximate time at which the "free" radium content in the tailings becomes insignificant in comparison with the "permanent" base level source of radiation within the tailings. With little doubt this "permanent" base level is significantly less than the radioactive level of the ore horizon outcropping extensively throughout the Morrison Formation in the area.

REFERENCES TO APPENDIX B

Nelson, J.D. and Shepherd, T.A. 1978. Evaluation of Long-Term Stability of Uranium Mill Tailing Disposal Alternatives, Final Report, Prepared for Argonne National Laboratories, April 1978.

Nuclear Regulatory Commission. 1977. Fuel Processing and Fabrication Branch, Uranium Mill Tailings Management, 1977.

Woodward-Clyde Consultants. 1978a. Tailings Management Plan, Proposed Ore Processing Facility, Shootering Canyon Uranium Project, Utah, Revised June 1978.

Woodward-Clyde Consultants. 1978b. Tailings Management Plan and Geotechnical Engineering Studies, Shootering Canyon Uranium Project, Utah. Prepared for Plateau Resources Limited, September 1978.

APPENDIX C

ANALYSIS OF GULLY EROSION

A key issue in the evaluation of the natural basin with impoundment dam alternative and the combination pit with containment dike alternative is the rate of erosion of the impoundment dam or dike by gullying.

No systematic analysis of long-term (i.e., thousands of years) gully erosion was found in the literature, so a simple model was developed. This model analyzes the rate at which a gully will cut through the crest of a dam or containment dike. The analysis derives the rate of erosion as a function of the conditions prevailing at the site.

This model is intended to provide general guidance as to the rate of erosion that might be expected. It does not model the process in detail. The results given by the model should be considered a first approximation of a complex event and not a precise portrayal of what may be expected.

Overview of the Analysis

For the analysis it was assumed that the critical gully would extend from the toe of the dam to its crest. The operative erosive force would

be the water falling in the exposed area of the gully. The amount of sediments that this water could transport would depend primarily on the grain size distribution of the material exposed in the gully and the slope of the bottom of the gully. However, for this analysis the simplifying assumption was made that the running water could, on the average, remove an amount of sediments equal to about 1 percent of the weight of the water. Although the true transport capacity of the running water would change during the life of the gully (primarily due to the flattening slope of the bottom), it is believed that the transport capacity would always be less than assumed, and therefore the analysis would be conservative.

With these assumptions the model was constructed as follows. First, a geometry for the gully was assumed. The exposed area of the gully was then expressed as a function of the depth of the gully. The rate of erosion of the material was related to the size of the exposed area* and the rate of rainfall. In addition, the rate of deepening of the gully would be a function of the rate of material loss. From this, a differential equation was developed which expressed the rate of deepening as a function of the rainfall rate. This differential equation was solved to give the depth of the gully as a function of time.

---

*The volume of water falling in the gully would be proportional to its area, and the amount of material eroded would be proportional to the amount of water. Hence, the rate of loss of material would be proportional to the exposed area of the gully.

Geometry of the Gully

The bottom of the gully was assumed to be straight and to pass through the toe of the dam. Figure C-1 shows a cross-sectional view of the assumed gully. In this view the dam has been characterized as a wedge, since our concern is limited to gullying on the downstream face of the dam.

The sides of the gully would stand at the angle of repose for the dam materials. It was assumed that these materials would be granular and noncohesive.

As may be seen in Figure C-3, these assumptions lead to a gully which, when viewed from above, would be wider at the top than at the bottom. Aerial photographs of the general area show a wide variety in gully shapes, but a substantial number do have roughly this shape, indicating that the assumed geometry is reasonable.

Derivation of the Model

In Figures C-1, C-2, and C-3 the pertinent dimensions of the assumed gully are labeled. The following equations were derived from them:

The volume of material removed from the gully as a function of the depth would be:

$$v = \frac{1}{3} \cdot H \cdot g^2 \cdot \tan \phi \qquad \text{(C-1)}$$

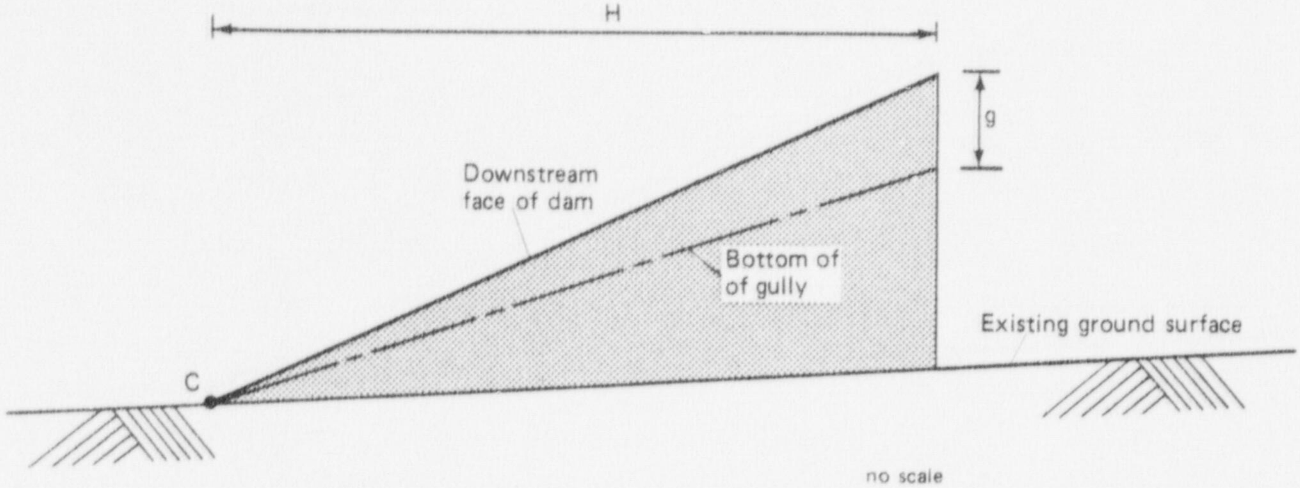


Figure C-1. CROSS SECTIONAL VIEW OF DAM AS IDEALIZED

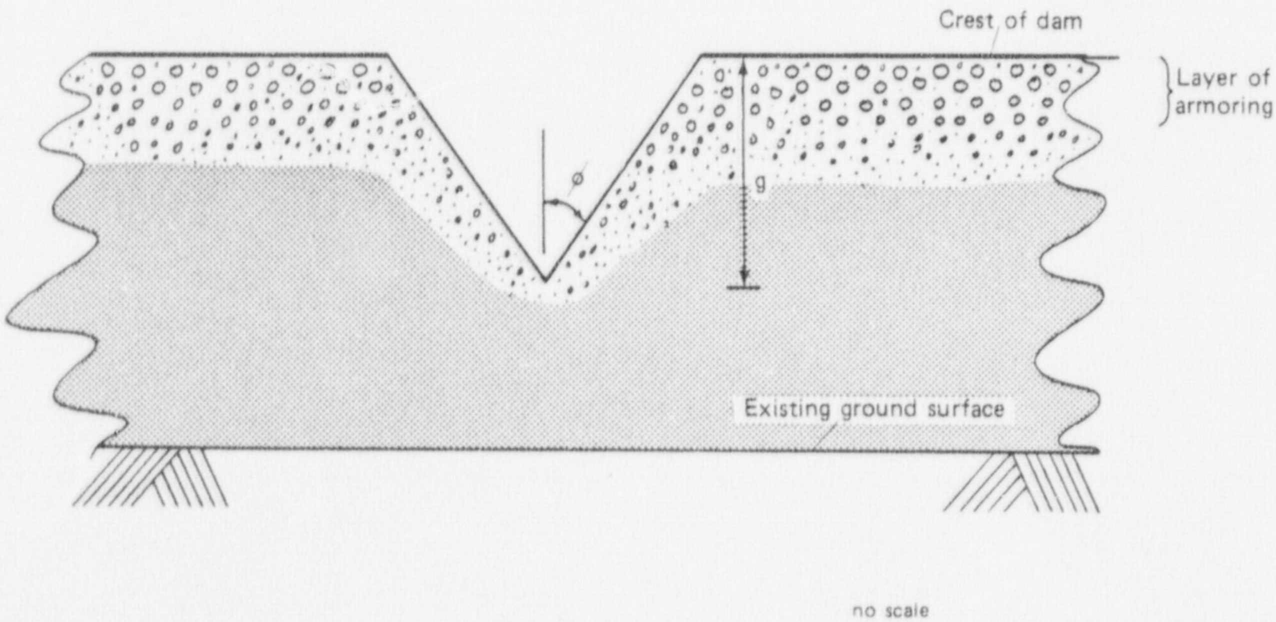
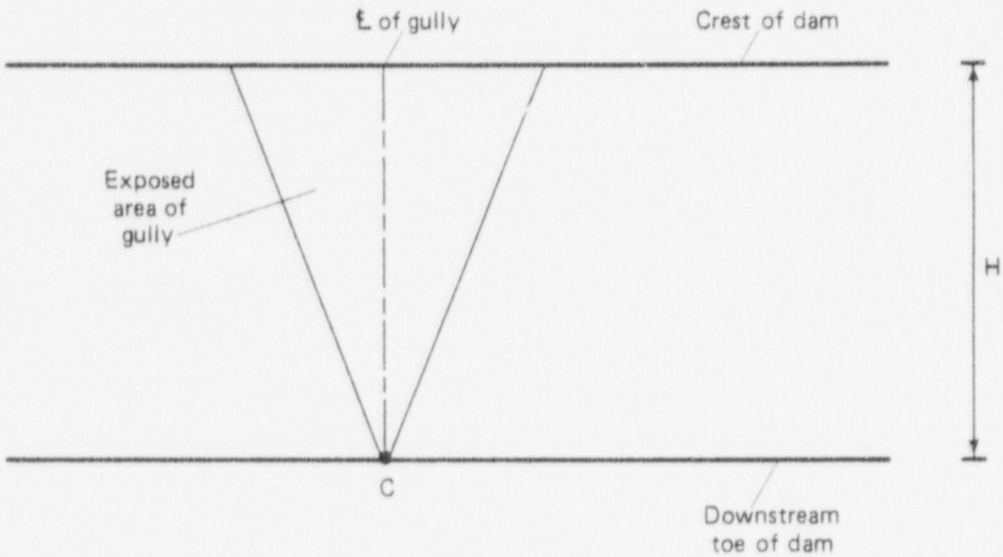


Figure C-2. CROSS SECTION OF GULLY AS VIEWED FROM UPSTREAM



no scale

Figure C-3. PLAN VIEW OF GULLY

where

v = volume of material removed from gully (ft^3)
H = horizontal distance from crest of dam to toe (ft)
g = depth of the gully at the crest (ft)
ϕ = angle of repose of material, measured from the vertical (degrees)

The exposed area of the gully as a function of depth would be:

$$a = H \cdot g \cdot \tan \phi \tag{C-2}$$

Letting W equal the rate of rainfall in (ft/yr), R equal the fraction of the rainfall that runs off, and S equal the volume of material eroded per cubic foot of runoff water, the rate of loss of material from the gully, as a function of the exposed area of the gully, would be:

$$\frac{dv}{dt} = a \cdot R \cdot S \cdot W \tag{C-3}$$

Substituting (C-2) in (C-3) we have

$$\frac{dv}{dt} = g \cdot H \cdot R \cdot S \cdot W \cdot \tan \phi \tag{C-4}$$

From equation (C-1) dv can be found as a function of dg by differentiating:

$$\frac{dv}{dg} = \frac{2}{3} \cdot H \cdot g \cdot \tan \phi \tag{C-5}$$

or

$$dv = \frac{2}{3} \cdot H \cdot g \cdot \tan \phi \cdot dg \tag{C-6}$$

Substituting (C-6) into (C-4)

$$\frac{\frac{2}{3} \cdot H \cdot g \cdot \tan \phi \cdot dg}{dt} = g \cdot H \cdot S \cdot R \cdot W \cdot \tan \phi \tag{C-7}$$

Simplifying, we obtain:

$$\frac{dg}{dt} = \frac{3}{2} \cdot S \cdot R \cdot W \qquad \text{(C-8)}$$

This implies that the gully would deepen at the crest at a constant rate which is independent of H and ϕ. This rate would be applicable to both the dam of the natural basin alternative and the dike of the combination excavated pit and containment dike alternative. The depth of the gully as a function of time may be calculated by integrating (C-8) and obtaining:

$$g = \frac{3}{2} \cdot S \cdot R \cdot W \cdot t \qquad \text{(C-9)}$$

where

t = time in years

Evaluation of Equation (C-9) For the Conditions at Shootering Canyon

First it was necessary to derive an estimate for S, the relation between volume of soil eroded and volume of runoff. Soil is approximately twice as heavy per unit of volume as is water (100 to 150 lbs/ft^3 for compacted soil, 62.4 lbs/ft^3 for water). Since it was assumed that the runoff would carry a sediment load equal to 1 percent of its weight, 1 cubic foot of runoff would erode about 0.005 cubic foot of soil. Thus S equals 0.005.

In the case of Shootering Canyon, rainfall, W, averages 6 to 8 inches per year. Assuming 8 inches per year, W equals 0.67 foot per year.

Considering the coarse-grained, pervious material to be used for the dam, it was conservatively assumed that 20 percent of the rainfall on the gully would result in surface runoff. Thus R equals 0.20.

Inserting the above values in (C-9):

$$g = \frac{3}{2} \cdot 0.005 \cdot 0.20 \cdot 0.67 \cdot \frac{ft}{yr} \cdot t \qquad \text{(C-10)}$$

or

$$g = 0.0001\ t\ . \qquad \text{(C-11)}$$

This implies that the gully would deepen at a rate of about 1 foot per thousand years.

REFERENCES TO APPENDIX C

Dames & Moore. 1978. Design Report, Proposed Tailings Impoundment, Anderson Uranium Project, Yavapai County, Arizona. Appendix D.

Nelson, J.D., and Shepherd, T.A. 1978. Evaluation of Long-Term Stability of Uranium Mill Tailings Disposal Alternatives. Final Report. Prepared for Argonne National Laboratories, April 1978.

Nuclear Regulatory Commission, Fuel Processing and Fabrication Branch. 1977. Uranium Mill Tailings Management, 1977.

Woodward-Clyde Consultants. 1978a. Tailings Management Plan, Proposed Ore Processing Facility, Shootering Canyon Uranium Project, Utah. Revised June 1978.

Woodward-Clyde Consultants. 1978b. Tailings Management Plan and Geotechnical Engineering Studies, Shootering Canyon Uranium Project, Garfield County, Utah. Docket No. 40-8698. Prepared for Plateau Resources Limited, September 1978.