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INFILTRATION TRANSPORT OR MIGRATION RATES OF RADIOACTIVE NUCLIDES AND OTHER TOXIC IONS AT THE SHITAMARING CANYON MILL TAILINGS IMPOUNDMENT

for

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October 19, 1984

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In conjunction with the development of a new mill to handle the uranium ore being produced in expanding mine facilities nearby, an impoundment was created in an isolated valley, the floor of which was elevated between 100 and 200 feet above prevailing stream courses in the general area. The first phase of the impoundment dam included a clay cutoff through the valley alluvium and a substantial clay core as well as filters and bulking fill. In the vicinity of the upstream toe of the impoundment dam, a clay apron was created over the valley floor along with a narrow band covering the bottom of the dry stream course (swale) upstream for some distance. Further upstream, special cells were created for the placement of tailings slurry that included a subsurface drainage network for the purpose of separating the tailings filtrate from the solids. The network led in turn to a sump at the downstream toe of a cross-valley berm that had been created to separate the cells from the main impoundment pool immediately behind the dam until storage needs warranted use of the latter.

The intent of the filtrate separation network and sump was two-fold. First, it allowed the recovery of solutions needed for separation of the uranium from the ore (primarily sulfuric acid). While the mill was on-line these solutions were recycled to the mill to help keep raw material costs at a minimum. Second, the operation of the self-draining cells for tailings wastes early in the life of the mill would make it possible to complete the use of storage capability high in the valley at an early date and would allow reclamation efforts to initiate at a time prior to complete filling of the impoundment. Early initiation of

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Date: 10/19/84 — rec'd. by fwg 11/9/84
By: WCC

reclamation efforts would help minimize dusting and other problems while at the same time allow investigations of what reclamation procedures would be most successful in this climate and terrain.

Prior to the completion of the mill, there was a substantial demand for electric power on the mill site and the immediate vicinity. In part, this need was justified by the demands of the mill construction itself but it was also justified by the electrical requirements of a number of air-sampling monitoring stations at locations around the perimeter of the mill and impoundment sites. In relative terms, these locations were remote to the mill itself and required the use of cables to transmit adequate power to them.

In response to these overall needs, three large (850 kw each) diesel generators were installed that required cooling water for efficient operation. This cooling water passed through an open loop water circuit in thermal contact with the ethylene glycol-filled engine cooling jackets. During mill operations, this heated water would be used in process. After the diesel generators were placed in service in late 1980, the water used for cooling was stored in temporary hypalon-lined ponds on the mill site and used for fugitive dust control on haul roads and ore stockpiles that had begun to accumulate at the site. By mid-summer 1981, however, the capabilities for storing or using the generator water had been exceeded and the excess was routinely diverted to the clay apron located at the upstream toe of the dam for storage.

Following commencement of mill operations in mid-April 1982, all generator water was diverted to the process circuit. About a week later disposal of tailings initiated into the first cell. Within one more week, tailings filtrate began to accumulate in the sump with essentially the same composition as the tailings-bearing solution discharged into the cell. Two weeks later (about May 8, 1982), the recycling pump failed due to abrasive wear of the mechanical seal for which replacement parts were not available on site. A cast iron pump with mild-steel impeller was

substituted. However, due to the high acidity of the solution being pumped, the operation of this pump was intermittant and by the time the original pump had been repaired and placed back in service (about May 18, 1982), the substitute pump was ruined. Operations continued with the repaired original pump until it failed again during the third week of August. It was repaired again and placed back in service during the second week of September. In the meantime, a standby pump had been acquired about the end of August that also proved capable of handling the entire sump flow.

During the periods that the recycling was not possible due to pump shut-down, an estimated two million gallons of tailings filtrate flowed down the clay-lined valley swale and entered the area of the clay apron behind the dam, already filled with approximately five million gallons of generator cooling water. During the period that followed, the peak water level in the clay apron pool reached a level of about 15 feet above the clay liner. Most of the unlined area so exposed to this somewhat diluted tailing solution was relatively high-slope Entrada Sandstone rock.

Following termination of mill operations in 1983, efforts were commenced to reduce the fluid levels in the pool. These included use of sprays in the upper and lower impoundments to enhance evaporation rates and to maintain wet tailings beaches in the upper impoundment. In addition, some of the solution was routinely pumped from the lower to the upper impoundment. Because of strength and permeability restrictions in the cross-valley berm and to preclude wash-over into other cells, however, only small quantities could be handled in this manner. Nonetheless, by late April 1984, sufficient quantities of water had evaporated or had been transferred to make it possible for the rest to be removed from the clay apron pool by May 8, 1984.

2.0

PURPOSE OF THIS REPORT

Purpose of this Report

The purpose of this report is to provide an evaluation, based on limited existing data relative to the problem, of the probable extent of migration of tailings solution, its radioactive contents and its content of potentially toxic ions beyond the confines of the impoundment. Of primary concern is the potential for these components to contaminate ground and surface waters in the vicinity of the site and beyond. Of concern also is the potential need for clean-up in the clay apron area and the degree that may be necessary, if any. Recommendations in this regard based on limited surface and near-surface testing of the now exposed "soils" in the area as well as the evaluation of the problem are included.

3.0 LATERAL TRANSPORT

3.1 GRADIENT

Over a period of five years (1979-1984) water levels in the rad. monitoring (RM) wells located around the impoundment were determined several times each year. With a general surficial gradient leading southerly for the impoundment valley, RM-1 was located to the north, RM-2 to the east, RM-3 to the west and RMs 4, 5 and 6 were located on the south side spanning the original dry stream course leading from the valley.

With the onset of dam construction, RMs 4 and 5 were extended 31 and 32 feet upward, respectively, in order to preserve them as monitoring wells as the downstream toe of the dam fill was extended over their position. RMs 4, 5 and 6 were all located downstream of the dam core and cutoff wall.

This group of six RM wells are, at present, the only borings penetrating the Entrada sandstone in the immediate vicinity of the impoundment. During the construction, each was bored into the Carmel formation and then plugged back to the base of the Entrada. As a consequence, each of the borings penetrates the entire Entrada section available at their respective positions in the valley. For the most part, this represents essentially all the Entrada formation for RMs 1, 2 and 3 and is short 50 to 100 feet for RMs 4, 5 and 6 due to prehistoric erosion of the valley floor. The exact thickness of the Entrada is not known precisely because of structural contortions in the area that took

place prior to consolidation in the rock form. It is clear, however, that in excess of 400 feet of sandstone lies above the Carmel in every RM position and that at least 130 feet of the formation was dry or unsaturated below the valley floor prior to the storage of generator water.

Despite the use of the impoundment for storing uranium tailings solid and liquid wastes in the upper reaches of the valley since the mill began operation and the pool area immediately above the dam for storing generator cooling water, the change in groundwater levels in the monitoring wells (all external to the impoundment) has been insignificant. This is to say, the levels are essentially the same now as they were in 1979.

These levels have been evaluated to determine a hydrologic gradient over the extent of the valley and particularly for that exiting the valley in the area at the downstream toe of the dam. Roughly speaking, the groundwater gradients orientations are as would be forecast from the present surface drainage with gradients leading toward the pool area from the higher lands on the north, east and west and from the pool toward the south. The lowest levels were observed in RM-6, drilled in one of the archaic stream channels leading from the valley. The overall gradient from RM-1 on the north to RM-6 is (10/18/80 determination) 10.61 feet per thousand. A vector determination using RM-3, RM-5 and RM-6 for the general area of the pool obtains approximately the same gradient for that area, 11.68 feet per thousand.

3.2 FLOW VELOCITY IN THE SATURATED ZONE

In previous reporting (Environmental Report 1978) actual determinations on the water-filled section of the Entrada formation just east of the impoundment provided a value of average permeability of 2.64 E-5 cm/sec by step-drawdown tests. This corresponds to a value of 27.3 feet per year.

Formation flow velocity (average) can be found by obtaining the product of the permeability and the gradient. In this case, the horizontal velocity would be

$$27.33 \times 0.01168 = \underline{0.319 \text{ ft/year}}$$

3.3 RELATION TO POINTS OF GROUNDWATER EMERGENCE

The nearest points of groundwater emergence known to exist are the seeps in Shitamaring Creek to the west of the impoundment, Lost Spring to the north of the impoundment and the small spring near Ant Knolls to the south. Although the location and elevation of these sources of groundwater have never been surveyed in for this project, it is estimated from the USGS topographic map of the area (Mt. Ellsworth Quadrangle 1953, updated 1970) that the following information is applicable to these sources.

Table 3.1 NEAREST SPRINGS AND SEEPS

Source	Source Elevation, msl	Straight Line Distance from RM-6
Shitamaring Seep	4230	0.50 mile
Lost Springs	4470	1.25 mile
Ant Knolls Spring	4300	0.65 mile

As may be seen both springs lie at a substantially higher elevation than the water level in RM-6 (4242.8 ft, msl) while the elevation of the seep water in the creek is slightly lower than that in RM-6. With a gradient of 4.8 ft/thousand along with geologic structure barriers between the impoundment and the creek, water movement would have little tendency to feed directly from the impoundment toward the creek.

Evaluation of the gradient along the creek (from the seep(s) to Cane Spring) shows a value of 10.24 feet per thousand, approximately identical to that in the impoundment area and with roughly the same orientation, i.e., north to south. It is most likely, then, that water movement from the impoundment area would continue to move on a south southwest course for at least 1 1/2 to 3 miles before merging with the general alluvial base fed by both Shitamaring and Hansen Creeks.

4.0

APPRAISAL OF VERTICAL FLOW

The presence of at least two springs in the Entrada at substantial elevations above the general water table shows the presence of perched water in the highlands to the north and southeast of the site and demonstrates that the vertical permeability of the Entrada ranges significantly from moderately low to virtually impermeable.

This conclusion was verified by geotechnical borehole testing prior to the construction of the dam in which packer determinations made to a depth of 100 feet (in the vicinity of the dam and RM 5 and 6) showed horizontal permeabilities ranging from 2 E-6 to 6.8 E-5 cm/sec with some narrow friable zones slightly higher. Interspersed between these zones was relatively impermeable rock. Below a claystone "marker horizon" the porosity dropped sharply and permeabilities as low as 6.5 E-7 cm/sec were obtained. The average value of 2.64 E-5 cm/sec obtained by the step draw down test quoted earlier for the saturated zone was interpreted as being a weighted average of such low permeability and "impermeable" layers continuing from the unsaturated into the saturated zone.

Pursuing this premise and using 6.8 E-5 cm/sec for the more permeable zones and 6.5 E-7 cm/sec for the less permeable zones, the weighting can be shown to be 38.6% of the former and 61.4% of the latter. Taking the commonly used approach that vertical permeabilities are on the order of 1/10th that of the horizontal, a composite vertical permeability can be calculated for the unsaturated zone underlying the impoundment.

Assuming the closest approach of groundwater to the base of the impoundment is 130 feet, then under the above assumptions 61.36% of 130 feet would have a vertical permeability of 6.5 E-7 x 0.1 = 6.5 E-8 cm/sec and 38.64% of 130 feet would have a vertical permeability of 6.8 E-5 x 0.1 = 6.8 E-6 cm/sec. Following A. R. Jumikis (Soil Mechanics 1962, p. 261)

$$Kv = \frac{L}{\frac{L_1}{K_{1\perp}} + \frac{L_2}{K_{2\perp}}} = \frac{130 \times 30.48 \text{ cm/ft}}{\frac{79.768 \times 30.48}{6.5 \text{ E-8}} + \frac{50.232 \times 30.48}{6.8 \text{ E-6}}}$$

where:

Kv = effective overall vertical permeability

$K_{1\perp}$ = vertical permeability of less permeable section

$K_{2\perp}$ = vertical permeability of more permeable section

L = overall thickness of horizon

L_1 = thickness of less permeable section

L_2 = thickness of more permeable section

Kv = 1.053 E-7 cm/sec or 0.109 ft/year

Two scenarios can now be assumed. First that a fifteen foot head of water existed in the pool behind the dam for a long period - long enough for a groundwater mound to have built up to the base of the impoundment (highly unlikely in any case since the horizontal permeability in the saturated zone is higher than the composite vertical permeability in the former unsaturated zone). For this case, the vertical hydrostatic differential would be

$$(130 + 15) \div 130 = 1.12 \text{ ft/ft}$$

and the vertical velocity would be

$$1.12 \times 0.109 = 0.122 \text{ ft/year}$$

The other scenario would be that a very low permeability zone existed at or near the surface of the bottom of the impoundment (highly likely for known conditions) and that the head differential was completely expressed across it. Two permeabilities can be considered, the Kv composite of 1.053 E-7 cm/sec or the slightly lower value determined for vertical permeability of the less permeable rock, 6.5 E-8 cm/sec. Since the former represents the more conservative viewpoint from the standpoint of potential radionuclide transport, it was used in the development of the following table.

Table 4.01 CALCULATED VERTICAL FLOW VELOCITY AND PROBABLE PENETRATION

Assumed Thickness of Low Permeability Layer, Ft	Apparent Velocity Velocity Through Layer Ft/Year	Penetration in 2 years' Time, Ft
1	1.635	3.27
2	0.8175	1.64
3	0.545	1.09
4	0.409	0.82
5	0.327	0.65
6	0.273	0.55

As may be seen, the low permeability layer limits the vertical velocity as well as the total penetration to relatively low values.

5.0

TESTING OF IMPOUNDMENT BASE

At the time prior to active use of the impoundment, essentially all loose soils had been removed and stockpiled or used for construction of the cross-valley berm and cell-wall dikes so that in most places only sandstone was exposed on the pool bottom. Most of this was subsequently buried in the flatter portions by a layer of clay, 2-3 feet thick. The bulk of the rest of the impounded area was represented by moderate to highly sloping rock walls that were weather and erosion resistant.

At the time of the spill, it is estimated that five million gallons of generator cooling water (obtained from wells in the Navajo Formation) were contained in the impoundment at a level that had already exceeded the limits of the clay liner. During the period of pump problems, the fluid level behind the dam raised to a peak of 4380 feet msl, some 15 feet above the clay liner.

Analyses made of the tailings fluid remaining in the cells a month after the initial spill showed a pH of 1.1. At the same time, analyses in the pool showed a pH of 1.7. The estimates of volumes of generator water and tailings solution were based on height/volume charts prepared for the impoundment and are rather closely verified by volume weighted evaluation of the observed pHs (pHs estimate total volume of fluid to be ≈ 7.96 million gallons).

The present condition of the site, following two years of at least partial immersion by the tailings fluid mixed into the stored generator water, includes a small pool covering part of the clay-lined valley swale

in the area where it adjoins the clay apron at the dam. Over the period from 1982-1984 checks of this fluid for chemical components show that evaporation must have accounted for the bulk of the fluid removal from the original pool.

Reaction between the acidic fluid and the rock undoubtedly took place. The exposed surface below the high water line is now covered by an unconsolidated soil about six inches deep, followed by about a foot of "rotten" rock, then one-half foot of medium-consolidated sandstone. At two feet below the surface, hard, well-cemented and unrippable sandstone was encountered.

For the areas trenched, it is difficult to determine how much of the unconsolidation now found is due to acid attack on solid rock and how much may merely represent remnants of the unconsolidated soil base that was left during construction or that may have developed as a result of wind drifting following construction.

It should be noted that in six determinations of pH of the pooled fluid from 6/82 to 4/84, the pit remained remarkedly constant at 1.7 $\pm$ 0.13 while the sulfate levels rose by a factor of 30 in the same period. Despite periodic dilutions during the rainy seasons, losses of water by evaporation for this site over this period are thought to have averaged between 4 and 6 feet annually. Given the probable continuous decrease in volume of the fluid, the high sulfate level (most of which was in the form of the bisulfate, $HSO4^-$) and the high ionic strength of the solution; the pH was probably held more or less constant by the sulfate/bisulfate buffering.

Although samples of fresh rock from depth (taken during foundation testing prior to dam construction) were noted to contain about 10% calcite, long exposed surfaces at outcrop undoubtedly contained far less. Assuming the six-inch residuum presently on the site to have resulted from acid attack, the rock exposed to the acidic spill probably had less than 2% calcite in the zone near the surface.

On-site studies of radioactivity distribution through this present regolith, in the eastern arm of the impoundment area where the highest activities were observed, showed a general increase with depth with a moderate peak just below the 6-inch level, which then increased further to a stronger peak at the 18-inch level after which it decreased rapidly to low levels. This distribution would appear to conform with changes likely to have taken place in the soil pH and potential for fluid penetration and subsequent drainage once the pool level became depressed. The high peak is seen as the zone in which the pH rose sharply due to interaction with high calcite values above a zone of virtually impermeable rock that had suffered little, if any, attack by the infiltrating solution. This determination was made in a small cut into the bank of relatively high slope. It is surmized that the two peaks may have generated from relative transport from vertical and horizontal directions - possibly at times of different pool elevation.

6.0
RADIOACTIVE ION TRANSPORT

The foregoing discussion of water movement rates below the ground surface serves as the basis for consideration of the migration of radioactive nuclides from the impoundment, in that groundwater flow provides the only significant means by which these nuclides can move. Hence, the flow rates and geometry of the groundwater movement are controlling and limiting.

In general, the movement of ions or charged particles of various kinds are attracted by opposite charges fixed-in-place in the soil/rock matrix and are said to be adsorbed by the soil. This action, in effect, retards the movement of the ions relative to that of the water, resulting in a lower relative velocity through the geologic material than would be characteristic of the water. Some fifteen years ago, Hajek developed the following relationship for this relative velocity:

$$\frac{Vi}{V} = 1 + \left[\frac{Kd*Bd}{e}\right]^{-1}$$

where:

Vi = velocity of ion in question in soil or rock
V = velocity of water through soil or rock
Kd = distribution coefficient
Bd = bulk density (dry density of soil/rock)
e = effective porosity (actual void space that can be filled with water)

The ratio Vi/V provides a value for the velocity of the ion through the soil relative to that of the water--the latter being determined by the permeability and gradient as before. This ratio is also called the retardation coefficient. The distribution coefficient (Kd) is dependent on the ion valence and the presence of competing ions in solution. It can be visualized that all positive and negative ions in solution are attracted to opposite charges fixed-in-position in the soil matrix. The presence of other ions in solution also influences the relative size of the hydrated ions, so the actual controlling aspect appears to be that of charge density on the outside of the hydrated ion along with its respective size, mobility etc. Clearly, the smallest ions are likely to have the least hydration (because of steric relationships) and thereby will be the most mobile. The ions with the highest charge density are the most likely to be held tightest by fixed-in-place electrostatic charges in the soil. When these two aspects are combined in the same ion, it becomes a formidable contender in the competition for available fixed charges.

The determination of Kd's is customarily made in the laboratory where samples of the soil or rock are dispersed in whatever solution is being tested, stirred well over a period of about 24 hours and the concentration of the ion in question determined in both the solution and the soil. Strickly speaking, the ion must be soluble in the solution over the range of concentrations being tested. From a practical standpoint, this is rarely the case with heavy metals, radionuclides derived from uranium and thorium, and with some of the other toxic elements. Carbonate is sufficiently ubiquitous in the environment in general and in soils or rock in particular that its presence always is a consideration where determinations of Kd are intended to represent the adsorption coefficient of the soil. However, given that the only intent is to find out what the retardation of the specific ion is relative to water movement, it is of little significance what mechanism is acting to hold the ion on the soil. Determinations of retardation coefficient then represent composite effects of solubility, ion adsorption, ionic strength, pH etc. in practice.

For this particular site, such studies were performed using a number of different types of geologic formation materials available on site or in the site vicinity. In that it was anticipated that the characteristics of the solution were likely to change with time due to evaporation, dilution, neutralization by interacting with carbonate-containing rock etc., three ranges of probable solvent conditions were investigated. These conditions represented the most likely extremes of solution characteristics the radionuclides would encounter during the period of impoundment or attempted sojourn with migrating groundwaters. These extremes included strong acid; strongly buffered, relatively high ionic strength solutions of approximately neutral pH, and a dilute solution that would represent the effects of infiltrating rainfall or snow-melt.

Such determinations with natural radionuclides were made on the inherent content of these ions in the "soil" samples and thereby provided information directly applicable to the case in point. They also provided a means to estimate how other ions of concern may act. That is to say non-radioactive but potentially toxic ions, because of their similarity in form or particularly in charge density and size to one or more of the radionuclides being tested, are likely to act in a similar manner. Consequently, reasonable retardation coefficients can be estimated for those ions in the field situation as well.

The radionuclides in question for this site are principally those of uranium, radium (226) and thorium (230). Since the Entrada sandstone is the only formation in the vicinity immediately impacted by the spill and the only formation to which the ion-containing solutions would be exposed for miles down-gradient, were they to become mobilized, only data relative to that formation will be considered here.

The distribution coefficient is the ratio of the concentration of the ion in question in the soil to that in the solution that surrounds it. Frequently, this is a number that may range over several magnitudes,

depending on the conditions and the particular ion being considered. For reporting purposes, the Kd is commonly represented by the logarithm of the Kd or the pKd. Values of the pKd's for the Entrada Sandstone are shown in the following table:

Table 6.01. PKD'S FOR THE ENTRADA SANDSTONE

Solution Characteristics	pKd Uranium U(nat)	pKd Radium Ra(226)	pKd Thorium Th(230)
Rainfall/snow-melt (distilled water)	1.81	2.10	4.14
Neutral, high ionic strength (1N NH_4Ac)	1.83	2.07	3.92
Highly acidic (pH=1.9)	1.10	0.34	3.87

Representation of the distribution coefficient as the log is particularly useful for it approximates the effective valence of the ion in question. As may be seen in the table, for the non-acidic solutions both uranium and radium approximate a value of +2 in the environment. (UO_2^{+2} and Ra^{+2}). For thorium, on the other hand the pK values approximate 4, the dominant valence of thorium over this entire range of conditions.

6.1 ON-SITE RADIOACTIVITY MEASUREMENTS

Subsequent to draining the pool in May 1984 back to the confines of the clay apron, a period of two months was allowed for dessication and stabilization of the soil surface. In early July 1984, a series of gamma radiation readings were taken at sixteen positions in the impoundment. These readings were taken at one meter in elevation above locations slightly down-gradient from the highwater mark made by the pool that had occupied the area. At five of these locations, soil samples were also taken and sent off for analysis. These samples were located in the

southeast, northwest and east arms of the impoundment and one along the north shore of the main pool. all of these samples were taken from the surface. The position on the north shore also had an additional sample taken at 20-cm depth.

In September, three additional sets of samples were taken in the pool area by trenching in three locations (north, east, and west) to depths in excess of one meter and four other sample sets were taken at positions well above the maximum extent of the pool to the north, east, west and south to obtain background data for comparison.

The Table 6.11 summarizes the data obtained by these sampling efforts and provides comparable data obtained during earlier studies of the impoundment rock in the late 1970's.

As may be seen, the averages of the surface samples taken in July and September match fairly closely and for uranium and thorium are on the order of about three times the high average background. The radium, on the other hand, is about a magnitude higher. The July 1984 subsurface sample taken at above eight inches depth (20 cm) shows all three nuclides to be below the average background high values. The subsurface samples taken in September 1984 at depths greater than one meter show at least another magnitude drop in radium and thorium levels and nearly 40% drop in uranium levels.

Surface contact surveys along transects across the bottom of the now dry pool showed highest values along topographic high points and particularly in "salt" incrustations on the surface soil and on plant debris along the pool edges (primarily Russian thistle). One piece of crust sent for analysis showed moderately elevated levels of radium and thorium but 100 pi/gm of uranium. The July soil sampling showed a variability from virtual background levels to 94 pi/gm in the eastern arm of the impoundment. It is suspected that some of those soil scrapings incorporated substantial portions of the crust at some locations during the July study.

Table 6.11 SURFACE AND SUBSURFACE AVERAGE RADIONUCLUDE ACTIVITY LEVELS

	Earlier Studies Aug. (Lake 1970's)	Background Surface Sept 1984	Background @ 18" Depth Sept 1984	July 1984 Surface	July 1984 -20 cm (only one)	Impoundment Trench Surface Sept 1984	Impoundment Trench @ One Meter Sept 1984
Radionuclide	pCi/g	pCi/g	pCi/g	pCi/g	pCi/g	pCi/g	pCi/g
Radium-226	0.97	1.66	1.75	28.3	0.059	15.3	1.6
Thorium-230	8.05	8.73	0.576	22.0	0.584	27.3	5.8
Uranium-NAT	0.98	00.35	0.64	31.23	6.03	32.6	9.4

In any case, the nuclides in the pool have apparently concentrated at the near surface to levels that exceed background. However, their content in the underlying soil drops off rapidly with depth. On the average the soil content is at or below background levels at soil depths substantially smaller than one meter.

6.2 POTENTIAL FOR MIGRATION

From the earlier discussion, relative to interaction of the acidic tailings solution with the calcareous rock, one would surmise that the infiltrating solution would become neutralized and somewhat basic in nature. Such neutralization, in itself, would cause most metal ions to drop out of solution as precipitates or as absorbed ions on rock surfaces.

The earlier studies showed that in Entrada Sandstone uranium and radium were moderately adsorbed ($pK_D < 2$) and thorium was strongly adsorbed ($pK_D < 4$). The retardation coefficients for these ions can be estimated from Hajek's equation as the ratio of the ion velocities to that of the water. Assuming a bulk density of the rock to be 130 #/cf or 2.08 gms/cc and an effective porosity of 10%, the retardation coefficients would be as follows for various effective pKd's (or roughly ion valence):

Table 6.21 RETARDATION COEFFICIENTS FOR VARIOUS pKds

pKd	Retardation Coefficient (Vi/V)	Ion
0	0.04E-2	Radium in acid solution
1	4.78E-3	Uranium in acid solution
2	4.81E-4	Radium and uranium, neutral solution
3	4.81E-5	
4	4.81E-6	Thorium in all solutions

Thus, if water velocities are on the order of 1/3 meter per year, none of the nuclides would migrate far into the soil, although it is apparent that radium may prove to be the most mobile.

6.3 DEPTH OF PENETRATION

Although detail on nuclide distribution with depth in the pool bottom is lacking, it is possible to combine information from sampling that were taken at about the same pool level to obtain an estimate of nuclide penetration.

For this, the average surface activity for radium was used along with the radium level at 20 cm depth (soil sample 9) and the radium level at 100 cm depth (West trench bottom soil sample). Although the data is sparse, it does suggest on a log/log plot that the background level is reached at a depth of about 10-20 centimeters from the surface (i.e., 1/3 to 2/3 feet) or an average of about six inches that might warrant concern for action such as excavation and removal.

7.0

OTHER ELEMENTS OF CONCERN

Analyses of the pool water during the period from 6/9/82 to 4/2/84 had shown a number of ions to be present for which there might be concern relative to general water quality or toxicity. For consideration here, only the highest levels are shown in the following table. A comparative analysis for the present condition of the fluids in the cells is also included:

Table 7.01. OTHER ELEMENTS OF CONCERN

Element	Highest Values Lower Impoundment, ppm	Present Values in Cells, ppm
Fe	750	N.A
Mn	94	N.A
Cr	0.53	0.07
Mo	15.7	N.A
V	134	N.A
Cu	7.1	N.A
Cd	0.19	0.13
Pb	0.8	0.5
Hg	0	<0.001
Se	2.0	0.061
Ag	0.007	0.06
As	5.7	0.032
pH	(1.5)	(>5.0)

Although the most recent analyses are not as complete as those performed previously, it may be seen that the pH is approaching neutrality. This has been accomplished by continuously recirculating the fluids through the filter network underlying the cells to take advantage

of the relatively high calcibe content of the mine waste rock placed there for that purpose. Under the conditions of substantially increased pH, the elkements not analyzed can be assumed precipitazted or adsorbed. For the other, Chromium, [illegible]'um, and arsenic show 1-2 orders of magnitude reduction and cadmium and lead both show reductions between 30 and 40%. Only silver shows an increase.

Of these elements, the ones likely to be most mobile in the environment are silver, selenium, and arsenic, because of relatively low charge density. Silver is a monovalent positively charged ion that is fairly soluble in sulfate solutions. However, it would appear from the concentrations obtained recently in the cell fluid that its presence in solution is more controlled by the chloride ion presence and that its form in solution is in part unionized AgCl, in part $AgCl_2$, and partly dissolved unionized silver oxide.

The selenium and arsenic have similar chemistries under environmental conditions, with both acting as multivalent (2 and 3 respectively) negatively charged ions.

Selenium has been shown to adsorb to western soils or rocks in a way similar to uranium, despite the opposite charge of their ions. From this it may be surmized to find sufficient positive charges in the soil to effectively immobilize it where water velocities are low. Arsenic may act similarily although in the presence of precipitating iron and possibly manganese, it is likely to be removed as an insoluble compound.

Although the present levels of any of the ions found are reasonably low and could be expected to be even lower with dilution in the groundwater, the presence of uniorized soluble compounds (eg AgClaq) suggests that it might migrate with virtually no retardation relative to the water flow. In this case, where it appears the advance of the

infiltration is virtually minimal, this would not appear to be a problem. It might be noted further that unionized compounds are subject to covalent adsorption, but no such testing with local soils has yet been done (or warranted).

8.0

CONCLUSIONS

It would seem that the infiltration by contaminated waters into the Entrada Sandstone has largely been stemmed by the low vertical permeability of the rock. Migration of radionuclides and toxic ions of any node is restricted to a short distance below the existing bottom of the impoundment - due in part to the low water penetration rate but also due to the solution modifying influence of the relatively high carbonate content of the rock and the ion adsorption capability of the rock forming grains.

Potential contamination of existing groundwater under the site appears remote and of streamflow virtually non-existant.

DRAFT

Date: ______

By: WCC

9.0

RECOMMENDATIONS

Although the appraisal here supports a contention that little environmental impact has occurred as a result of the release of tailings fluids into the lower impoundment, a portion of which was unlined, there are certain actions to be recommended that would help to minimize any further migration of radionuclides or toxic ions.

These would include the following:

1) Remove all obviously contaminated organic debris

2) Excavate all loose soils from the contaminated area

3) Install controls at the sump to insure that runaway discharge from the cells cannot occur again, should the pump or other parts of the recirculation system fail

4) If there is reasonable potential for further mill activity, complete the clay lining of the impoundment behind the dam

5) Rework swale lining, enlarging and replacing where inferior clays were used or underlayment was too porous (e.g., residual alluvium) and significant crumbling or cracking occurred

6) Keep fluid level behind dam depressed and confined to at least the bounds of the present clay apron.

10.0

REFERENCES

In preparation.