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UMTRA PROJECT

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Mr. John D'Antonio
Department of Energy
c/o Jacobs Engineering Group, Inc.
5301 Central Avenue N.E., Suite 1700
Albuquerque, New Mexico 87108

Subject: UMTRA PROJECT - GEN
Review Comments on Documents for Working Group 4 - Water Resources

Dear Mr. D'Antonio:

I am enclosing my comments marked on a copy of the document, "UMTRA Project Technical Approach Document - Water Resources Protection" by the TAC Hydrological Services Group, discussed by the Workinggroup 4 at the August 6, 1985 meeting of the DOE, NRC, TAC and RAC in Albuquerque.

By copy of this letter, I am forwarding comments to John Thackston of the TAC and Mike Weber of the NRC.

Sincerely,

James T. Kam
Hydrologist

JTK:kfb

cc: John Thackston
Jim Oldham
Mike Weber

WM Record File

WM Project 39

Docket No.

PDR ☒

LPDR

Distribution:

Weber

DEM

(Return to WM, 623-SS)

Enclosure: Marked copy of "UMTRA Project Technical Approach Document - Water Resources Protection". (MKE Document No. 4005-GEN-R-04-00836-00)

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Project

UMTRA TECHNICAL APPROACH DOCUMENT

WATER RESOURCE PROTECTION

By the

TAC

~~E~~ Hydrological Services Group

for

The U.S. Department of Energy

JULY, 1985

* Comments by James T. Kan of RAC

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UMTRA - S. E.

PRELIMINARY DRAFT

3.3 PROTECTION OF WATER QUALITY

The United States Environmental Protection Agency (EPA) Standards (40 CFR Part 192) (EPA, 1983a) require site characterization of the hydrogeologic regime at and around each Uranium Mill Tailings Remedial Action (UMTRA) Project site. Also stated in 40 CFR ^{Part} 192 is the following requirement: "judgements on the possible need for remedial or protective actions for ground water aquifers should be guided by relevant considerations described in EPA's hazardous waste management system (47 FR 32274) (EPA, 1983b) and by relevant state and Federal water quality criteria for anticipated or existing uses of water over the term of the stabilization." Thus a hydrogeologic characterization of all alternative disposal sites is also required. The following section describes the generic technical approach that DOE will use to meet the EPA standards for water resource protection.

3.3.1 Characterization

The DOE will conduct subsurface investigations at each mill processing and potential tailings disposal site to define the presence and extent of significant ground water bearing units. Characteristics of each geohydrologic unit will be defined which are pertinent to determining the degree of present and potential contamination of ground water and surface water by the milling operations and tailings.

3.3.1.1 Background water quality

Characterization activities will include determining background water quality at all sites^a. Conceptually, background water quality is the water quality that existed in local surface waters and ground waters prior to uranium recovery activities. However, in some cases the ground water quality may have been affected by activities other than uranium recovery which occurred after the uranium milling. Because pre-uranium recovery data are generally lacking or are inadequate, samples assumed representative of background will be collected from nearby surface and ground water locations that are hydraulically upgradient from any known uranium recovery activities. Sample locations ²~~such~~ should be free of windblown radioactive contamination related to uranium recovery (i.e., as determined using scintillometer surveys). Also, these sampling locations should be hydraulically upgradient of areas that were affected by radial flow from the tailings site during active tailings disposal. Locations that have these characteristics and are thus reasonably representative of background water-quality will hereafter be referred to as upgradient sample locations.

^aNote: The following comments are intended as general guidelines for determination of background water quality. It may not be feasible to determine the real background water quality at some sites, such as those where several sources of contamination have impacted the periphery of a site. As such, all background determination activities will be performed on a case-by-case basis, employing the following guidelines whenever possible and practical.

Characterization of background water quality will proceed as follows:

a Review of existing data/literature. Such a review would include existing well and spring data (drillers logs, geophysics, and *and geohydrologic* geohydrologic water analyses), geologic/reports, maps, and surficial radiation surveys.

a Develop a preliminary conceptual model of ground water flow within the immediate vicinity of the site.

a Inventory, and describe existing water wells and springs in the site vicinity (i.e., within a two mile radius).



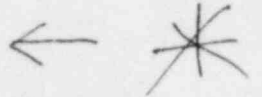
a ~~Augment~~ the existing upgradient sampling locations by installing additional upgradient monitoring wells.

a A goal of having approximately three upgradient sampling locations per geohydrologic unit has been established for the project. Chemical constituents to be determined will be selected from those listed in Table 1.

Table 1 Constituents and detection limits for water analysis

Constituents	Detection limit (mg/l)	Constituent	Detection limit (mg/l)
Chloride (CL)	1.0	Iron (Fe)	0.03
Sulfate (SO ₄)	0.1	Lead (Pb)	0.01
Sodium (Na)	0.002	Manganese (Mn)	0.01
Potassium (K)	0.01	Mercury (Hg)	0.0002
Magnesium (Mg)	0.001	Molybdenum (Mo)	0.01
Calcium (Ca)	0.01	Nickel (Ni)	0.04
Boron (B)	0.1	Selenium (Se)	0.005
Fluoride (F)	0.1	Silver (Ag)	0.01
Cyanide (CN)	0.01	Strontium (Sr)	0.1
Sulfide (S ²⁻)	0.1	Tin (Sn)	0.005
Carbonate (CO ₃)	1.0	Uranium (U)	0.003
Bicarbonate (HCO ₃)	1.0	Vanadium (V)	0.01
Ammonium (NH ₄)	0.1	Zinc (Zn)	0.005
Nitrite (NO ₂)	0.1	Total Dissolved Solids (TDS)	10
Nitrate (NO ₃)	1.0	Total Organic Carbon (TOC)	1.0
Nitrate & Nitrite	0.1		
Silica (SiO ₂)	2.0		
Phosphate (PO ₄)	0.1		
Aluminum (Al)	0.1	<u>Radionuclide</u>	<u>pCi/l</u>
Antimony (Sb)	0.003	Lead-210 (Pb-210)	1.5
Arsenic (As)	0.01	Polonium-210 (Po-210)	1.0
Barium (Ba)	0.1	Radium-226 (Ra-226)	1.0
Cadmium (Cd)	0.001	Radium-228 (Ra-228)	1.0
Chromium (Cr)	0.01	Thorium-230 (Th-230)	1.0
Cobalt (Co)	0.05	Gross Alpha	2
Copper (Cu)	0.02	Gross Beta	3

- o Vertical variations in background water quality will be defined by sampling a range of stratigraphic depths at the upgradient locations.
- o Compile a data set of background water quality data from the wells and springs described above. Background sites would be sampled quarterly for up to one year.

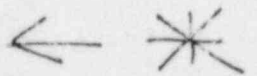


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These background data set could be augmented with water quality data from existing uncontaminated wells and springs yielding from the same geohydrologic or hydro-stratigraphic units within the region (e.g., within the same basin or watershed). Even though these regional data locations may be hydraulically downgradient as well as upgradient, they would be selected from areas well outside the contamination created by uranium processing. Such data would expand the background data set, making it more acceptable to determine background concentrations using simple statistical approaches.

Samples

Where six or more background data points are available, background constituent concentrations will be determined by compiling a table with the following headings:



because data points ^{may} ~~can~~ be from split samples which ~~are~~ not separately sampled.

Table 2 BACKGROUND WATER QUALITY

Constituent	Observed concentration range (ug/l)	No. of analyses	Mean \bar{X}_b	Two standard deviations ($2S_b$)	Back- ground conc. range
U Mo					10-20 ug/l

Background concentration ranges would be determined by calculating $\bar{X}_b \pm 2S_b$, or $\bar{X}_b \pm 2S_{QA}$, whichever results in the more comprehensive range. ($2S_{QA}$ is the value of two standard deviations in the precision data for the appropriate constituent, as determined from the quality assurance (QA) program).

* [Where less than six background data points are available, the background concentration range will be assumed equal to the observed concentration range of background data. Such a data set would be too small for meaningful statistical manipulation. If all values are below

(continue text)

This statement is rather vague; what if there is only one sample which exceeds background? We should use statistics to test if the conc. exceedance is significant provided enough samples are collected

detection limits of the analytical methods employed (as stated on Table 1), then the background values will be determined as less than or equal to the detection limit.

Background concentration ranges would be used as a basis for defining the areal extent of any contaminant plume. A contaminant plume is defined here in as a contiguous ~~are~~ ^{area} downgradient, beneath or adjacent to the site, defined by sampling locations having concentration levels of chemical parameters above the background range. *

3.3.1.1.2

Surface waters

As with ground waters, selection of background surface water sites will follow a preliminary data/literature review phase. Sampling locations will be chosen upstream of the site being studied in areas unaffected by known uranium recovery activities at that site. Water would be collected as grab-samples from either bank in a well mixed zone. Routine samples will be filtered through 0.45-micrometer membrane filters, and analyzed for constituents selected from Table 1. Where appropriate, unfiltered samples will also be collected and analyzed. *Water level and velocity should be measured in streams during monitoring* *

3.3.1.2 Presence and extent of contaminant plumes

3.3.1.2.1 Ground water

Major characterization tasks involve: 1) identifying the presence and hydrogeochemical and hydraulic properties of geohydrologic units which may lie along the flow path of contamination emanating from the tailings pile, and 2) determining the area and vertical extent of ground water contamination.

Steps necessary to characterize the extent of ground water contamination are:

- a. Compile preliminary data and review literature.
- a. Identify strata most likely to be/become contaminated.
- a. Develop a conceptual model(s) of ground water flow pathways. Using existing hydraulic, geologic, water quality, geophysical, and drilling data, develop preliminary estimates of the direction(s) of ground water flow, locations of hydrologic barriers, preferential flow pathways, estimated vertical leakage, etc. Concept development would include simple analyses


of flow using flow nets, Darcy's Law, or other appropriate methods, and applying assumed values of hydraulic conductivity ^{and storage coefficient} from the literature. *

Such analyses would provide gross indications of the potential extent of contaminant migration and would aid in designing the monitoring well network and aquifer tests.

- a Design preliminary drilling program. Selection of monitoring well locations would be intended to delineate the areal and vertical extent of the contamination. Emphasis would be placed on siting wells in strategic locations (i.e., near dwellings, rivers, drinking water facilities, likely discharge points, and between such locations and the tailings pile(s). Well siting decisions would also be based on insights gained from the previous conceptual modeling exercises. Vadose zone sampling of water may also be employed at selected sites.

- a Well siting and sampling. The first boreholes drilled for monitor well installation should be located near the contaminant source (e.g., tailings), in the presumed downgradient area and completed in a stratigraphic interval near the

Drilling with
air is preferable.

base of the tailings pile(s). Drilling methods and fluids will be employed which minimize the potential for spreading contamination. 



At most sites, water quality samples will be collected from all wells on approximately a quarterly basis for a period of up to one year. The constituents listed in Table 1 will be determined for all wells in the first two rounds of sampling. Following interpretation of these data, selected constituents (e.g., trace constituents not exceeding water quality standards) would be dropped from subsequent quarterly samples.

In addition, a single set of samples for analysis of Priority Pollutant Organic Compounds selected from CFR 440.3 will be performed at up to three wells completed immediately beneath and downgradient tailings of the pile. An additional upgradient well may also be sampled for such analyses. If significant concentration of Priority Pollutant Organic Compounds were detected near the pile, a decision to monitor for these compounds throughout the area would be made. Under the present scope of work, it has been assumed that such compounds are not normal components of uranium-recovery wastes. However, it is desirable to collect these reconnaissance samples for organic pollutants in order to thoroughly characterize the contamination at each site.

To define the extent of the contaminant plume, additional wells will be sited at progressively greater distances from the pile(s) until measured concentrations of contaminant indicators (e.g., sulfate, and specific conductance) approach their respective background levels or until a discharge boundary is reached. The majority of wells will be located in presumed downgradient regions. To define the vertical extent of the contaminant plume, selected sites will have several wells constructed close together and completed at differing intervals (nests). Selection of these completion intervals would be based on both the conceptual flow models developed for the site hydrogeology, and on field screening techniques employed during drilling. Such screening techniques for locating contamination include monitoring borehole waters for specific conductance, sulfate and chloride. Whenever possible, the deepest monitoring wells would be completed in zones below any contamination. Such siting decisions may be expedited by compiling water-level maps in the field.

PH, temperature
Iron, Color
Turbidity and CO₂

Ground water quality and hydrogeologic data will be synthesized into the following types of interpretive products to delineate the locations of contaminants:

- a Hydro/geologic cross-sections, including hydrochemical facies where possible.

- o Water quality cross-sections, delineating concentrations of contaminant indicator constituents with depth.
- o Plan-view, iso-concentration contour maps of contaminant constituents. ^{sta} (the maps will include well sample locations and concentrations).
- o Potentiometric surface maps.
- o Figures (graphics, tables, cross-sections) comparing measured contaminant concentrations to appropriate state and Federal standards.

• Concentration of Various indicator parameters (specific conductance, pH, chloride, iron, color, turbidity) vs. time for each monitoring well

• Water Balance Profile

3.3.1.2.2 Surface waters

The proximity of the site to surface water will be determined from available information, aerial reconnaissance or field surveys. A map will be drafted to show bogs, swamps, seeps, springs, ponds, lakes and streams relative to the site. Climatologic data will be obtained from the National Oceanic and Atmospheric Administration (NOAA) or the National Weather Service (NWS). These data will be used in the hydrogeochemical characterization of the impacted area.

Surface water samples will be collected from all rivers/streams and ponds within the immediate vicinity of the waste site (i.e. in the area where there is a reasonable expectation that a potential exists for degradation of surface water by the post uranium processing at a particular UMTRA site). Grab samples of streams will be collected in hydraulically downgradient locations that would be most likely to indicate surface water contamination. Sampling locations will be along the stream bank nearest potential contaminant sources (e.g., tailings accumulations). Routine samples will be filtered through 0.45 micron membrane filters, and analyzed for the constituents in Table 1. Where appropriate, unfiltered samples will also be collected and analyzed.

The presence of concentrations elevated above background of any contaminant constituents would indicate that future surface water sampling should involve depth-integrating procedures to better define the contamination degree and extent.

If significant concentrations of Priority Pollutant Organic Compounds are detected in site ground waters, a program to monitor similar compounds (especially those which are non-volatile) in surface waters would be developed.

Surface water quality data will be compiled into a form which will elucidate the degree and extent of contamination, if any, e.g., the data may be synthesized into graphs showing downstream concentration patterns of contaminant constituents. Relative locations of tailings piles will be noted on these graphs if appropriate and useful. In addition, tables and/or graphs may be constructed comparing the contaminant concentrations, if present, to appropriate state and EPA water quality standards and criteria.

3.3.1.2.3 Quality control of water analysis

Definition of chemical background and ^{contamination levels} ~~plume extent~~ require ~~exceptionally~~ reliable water quality data. To accomplish this, the following quality assurance/quality control procedures will be employed at all sites. Water samples will be divided into lots (groups) of approximately nine water samples or less. Accompanying each lot of samples from the field will be one prepared solution having known concentrations of chemical constituents. This known solution will include the majority of chemical parameters to be analyzed in the lab.

Comparison of the lab analytical values for the known solution with the known concentration values will

provide a basis for establishing the accuracy of the lab analyses of the other samples in the lot. If pre-established accuracy requirements for the lab results are not met the lab will be required to reanalyze the sample until acceptable accuracy is achieved.


Statistical
tests *

Precision of the analyses will be established by submitting a total of five replicate aliquots (identified as different samples) for one of the samples in each lot to the lab for analyses. The replicate analyses will be used to establish confidence intervals of sampling and analytical precision (error bars) which are indicative of the total error associated with each measurement. These confidence intervals will be tabulated and discussed in the interpretative sections of the report relating to background concentrations, and contaminant plume definition.

3.3.1.3 Movement of contaminated ground water

Uranium mill tailings are a potential source of ground water contamination. The contamination may move from the tailings to the ground water by gravity-driven saturated or unsaturated flow, and then be transported laterally within the ground water. Thus in order to assess the rate and direction of contaminant movement it is first necessary to characterize the contaminant source

and assess the vertical movement of contamination into the ground water. Then it is necessary to estimate the present rate and direction of ground water flow. Finally, the attenuative properties of the geohydrologic units need to be assessed to estimate the degree to which contaminants are retarded relative to the ground water flow rate. For all assessments of the rate and direction of contaminant movement, the most straight forward methodology available will be used to characterize and predict future impacts on water resources. Simplifying assumptions which result in conservative, defensible analyses will be employed as much as possible.



3.3.1.3.1

Contaminant source

The conceptualization or characterization of a contaminant source is a complicated process. As contamination in an aqueous form moves from the tailings into and through surrounding ground water, it is subject to continuous changes in quantity and quality by dilution reaction, dispersion, and attenuative processes. Many of the geochemical processes which affect the contaminants, collectively termed attenuation or retardation, are not easily quantified; yet they can cause order of magnitude changes in the concentrations of key contaminants. With these uncertainties in mind, several approaches for characterizing a contaminant source are presented below.

One approach is to view either the solid phase or the pore water within the tailings as the contaminant source. The solid chemistry of 12 tailings sites has been determined through assay of residual mineral values (DOE, 1985a), and has been determined at other sites through hydrogeochemical characterization studies (DOE, 1985a). Pore water in the unsaturated zone can be sampled using suction lysimeters; however, data from inactive tailings indicate that concentrations of many key contaminants may be reduced by several orders of magnitude between the tailings pore water or the tailings solids and the ground water. In order to use data on solid chemistry or pore water chemistry as a representation of a contaminant source, it is necessary to use methods which take into account alternative processes such as those listed below:

- o Geochemical models are available which predict stable mineral phases based on solubility controls or other processes. Such models have been successfully applied to an UMTRA Project site (Narisimhan et al., 1984).
- o Empirical equations describing retardation have been developed for radioactive waste (Gilbert et al., 1983) and have been applied at UMTRA Project sites (DOE, 1983).

Alternately, pore water concentrations could be used as the source concentration for those constituents known to be conservative, i.e., those constituents not appreciably attenuated.

A second approach to characterizing a contaminant source is to calculate what the apparent source would be based on observed concentrations and distributions of contaminants in the downgradient ground water. This may be done using an analytical equation of solute transport (DOE, 1984, ^{and} Domenico and Robbins, 1985). The calculated concentration of the source is then used in conjunction with predictions of volumetric flux of contaminants to predict movement.

A third approach to characterizing a contaminant source is to measure ground water quality directly below the tailings in the existing environment at more than one well, and use the worst quality as representative of the contaminant source.

3.3.1.3.2 Unsaturated zone movement

The volumetric flux of the pore water into the ground water should be estimated. Most of the UMTRA Project tailings have already drained to near their residual water content. The long-term movement of water

through the tailings and the unsaturated zone below will be a result of and, in most cases, limited to the amount of ^{Net} infiltration of precipitation. This infiltration will be estimated using one or more of the following methods listed in the order in which they will be considered for application on a site by site basis:

- o By assuming saturated flow into the tailings under a unit gradient, using Darcy's Law to calculate an upper-bound flux rate.
- o By assuming that saturated flow occurs only some fraction of the year and making calculations based on Darcy's Law (DOE, 1985b). The fraction of the year during which saturated flow occurs will be based on experimental data or meteorological data.
- o By using a simple algebraic water balance model, infiltration through a low-permeability cover will be assumed to be less than or equal to the existing infiltration rate.
- o By measuring spatial variations in concentrations of isotopic tracers (e.g., tritium) and calculating estimates of infiltration rates from the spatial distribution of the tracer,

✓ Infiltration through a low-permeability cover will be assumed to be less than or equal to the estimated present infiltration rate.

- a By using Darcy's Law modified for unsaturated flow (Hillel, 1971), ✓ Infiltration will be estimated based on in-situ measurements of matric potential and on measurements of unsaturated hydraulic conductivity, using the zero flux plane concept (Dreiss and Anderson, 1985).

Infiltration through a low-permeability cover will be assumed to be less than or equal to the estimated present infiltration rate.

- a By using a numerical model of unsaturated flow with assumed input parameter values representative of the site conditions, e.g., TRUST (Reisenauer et al., 1982), or a water-budget model of infiltration, e.g., the HELP model (Schroeder et al., 1983).

One or more of the above infiltration estimating methods will be used for a given site. Selection of a method(s) for application will be based on the extent and reliability of the available data and the required accuracy and precision of the values for infiltration rate considering the site hydrogeologic setting.

3.3.1.3.3 Saturated ground water flow

The saturated ground water flow rate (average linear velocity) and flow directions in the site vicinity will be characterized by obtaining site-specific hydrologic data from monitoring wells and aquifer tests. Data will be obtained to provide values for hydraulic conductivity, effective porosity, and hydraulic gradient for each hydrogeologic unit of concern at each processing and disposal site. These data will be used to calculate estimates of ground-water velocity from the Darcian flow equation:

$$V = \frac{K i}{\phi}$$

where

V = average linear velocity

K = hydraulic conductivity

i = hydraulic gradient

ϕ = effective porosity

*Continue with
text*

Hydraulic conductivity values will be estimated from aquifers pumping tests or slug tests using well-established techniques (e.g., Bouwer, 1978; Kruseman and DeRidder, 1983). The hydraulic gradient values will be estimated from potentiometric surface maps or flow nets constructed based on ground water level measurements in all monitoring wells in the vicinity of a site. The potential for seasonal fluctuations in the water table will be evaluated based on all available historical ground water level data. Effective porosity values will be estimated based on lab tests on core, aquifer tests, or values obtained from literature by previous investigators of similar geohydrologic units.

3.3.1.4 Attenuation of contaminants

In order to understand and predict movement of a contaminant it is necessary to identify the attenuative processes and estimate the attenuative capacity of the hydrogeologic environment.

Natural processes which promote attenuation (reduction) of contamination concentrations include mechanical dispersion, dilution, filtering of suspended or colloidal solids, biologic decomposition of organic compounds, ^{fe}denitrification of nitrate, ion exchange, precipitation of dissolved chemicals, ion sieving by dense clay layers (ultra [~]filtration) and decay of

radioactive elements (Bouwer, 1978). Each of the above processes will be considered in the evaluations of contaminant movement and prediction of impacts on the water resources in the vicinity of each UMTRA site. The following discussion describes the guidelines to be followed on ^{the} UMTRA Project for characterizing a site's attenuative capacity. Of particular importance are the expected chemical interactions between the tailings solution and the soil and sediment.

The neutralization capacity of the soil and rock beneath an acid mill tailings pile has been identified as the single most important chemical factor in determining the ability of geologic material to chemically attenuate the movement of contaminants (Shepard and Cherry, 1980). Neutralization is the main driving mechanism for mineral precipitation and adsorption in these systems. The rise in solution pH that characterizes neutralization produces a condition in which the solubility of Fe and Al oxyhydroxides decreases. These solids precipitate and scavenge several other contaminant metals (Mn, As, Se and Mo, etc.) from solution. Because carbonate minerals are usually the primary source of neutralization in the soil and sediment, determination of the carbonate content of the solid phase can be used to substantiate measurements of the neutralization capacity. The presence of even a small fraction of one percent of carbonate minerals is sufficient to provide considerable neutralization.

capacity. For this reason an analytical method that has a low detection limit will be chosen for determining carbonate content of the soil and rock.

Concentrations of some of the ~~20~~ constituents (SO_4 , U, As, Se, and Mo) often persist at elevated levels in the aquifer downgradient from the zone of neutralization. Chemical attenuation processes affecting these constituents in this environment are basically the same as those near the pile (i.e., mineral precipitation and adsorption), but chemical parameters other than neutralization capacity must be measured to estimate attenuation in this regime.

In cases in which the aquifer affected by the tailings is oxidizing, the higher valence states of the contaminant trace metals predominate. Under these conditions, the primary attenuation mechanism for U, As, Se, and Mo is adsorption onto clay minerals, onto organic matter, and, especially, onto ferric oxyhydroxides (Henry et al., 1982). Several types of laboratory analyses can be used to produce a qualitative estimate of a material's ability to attenuate the migration of these metals. These analyses include: cation exchange capacity, identity and concentration of exchangeable cations, clay content, quantity of metal oxyhydroxides, and amount of

organic matter. Some of these analyses are redundant, and provide a check on the reliability of the other measurements.

The quantitative results of the listed analyses give only a qualitative estimate of attenuation capacity because the expected rate of movement and concentration of the contaminants in the aquifer cannot be presently predicted. However, the qualitative measures will be sufficient to compare sites and make estimates of concentrations based on the observed movement of contaminants at sites with similar conditions.

At some sites the contaminated ground water may move into zones in which reducing conditions exist due to the presence of pyrite, reactive organic matter, or perhaps H_2S gas. Under these conditions, relatively insoluble mineral phases of the elements U, Se, Mo and, perhaps, As will be stable. Precipitation of these phases will lower solution concentration of these elements to below contaminant level, and the metal will remain immobilized as long as the pH/Eh condition is stable. In order to determine if mineral precipitation under reducing conditions is a reasonable attenuation mechanism in an aquifer, the presence of reducing conditions must be established. This can be done most directly by measuring the pH and Eh of the ground water, ensuring that the

solution is not contaminated by atmospheric oxygen during sampling. The presence of noticeable H_2S gas in the ground water, rock or sediment is also a good indication that strongly reducing conditions exist in the aquifer. If reducing conditions are expected to exist, the rock or sediment of the aquifer may also be analyzed for pyrite (Lord, 1982) and reactive organic matter (USDA, 1969) to give an indication of the reducing capacity and an indirect measure of the reducing intensity (Eh) of the sediment).

Sulfate is the one constituent of the tailings that will probably not have its concentration lowered below contaminant level by mineral precipitation or adsorption under either oxidizing or reducing conditions. Although the precipitation of gypsum, or perhaps an iron or aluminum sulfate phase, will lower sulfate concentration in the neutralization zone compared to the concentration in the tailings pore solution, it is expected that the dissolved sulfate concentration will remain above background levels after precipitation of these solids. Gypsum formed during neutralization near the pile may act as a relatively long-term source of sulfate in the aquifer. However, because neutralization reactions associated with the precipitation of gypsum also tend to reduce local permeability, the amounts of mobile sulfate beneath the pile are expected to be much less than prior to gypsum deposition.

Chemical attenuation mechanisms will be evaluated with regard to long-term impacts on water quality. Attenuation mechanisms decrease ground-water concentrations of contaminants, but a corresponding increase in the amount of contaminants in the solid phase occurs. If the contaminants in solution are immobilized by reaction with the sediment or rock then future ground-water contamination problems may be minimal, but if the solid phases (e.g., gypsum) are subject to further long-term reactions they may maintain contaminant levels well above background and perhaps above water quality standards for a considerable period of time. Minerals that are precipitated may dissolve and adsorbed species may desorb when normal ground-water conditions are re-established or during aquifer restoration efforts. Therefore, the response of the entire sediment/rock/water system to "normal" aquifer conditions that will be established after stabilization or movement of the tailings will also be evaluated.

3.3.2 Predicted concentrations

Once the contaminant source has been characterized, flow rates estimated and attenuative processes defined, one of the approaches described below will be employed for predicting the movement and future concentrations of contaminants.

As a conservative upper-bound estimate for migration rates, it can be assumed that contamination will move in the same direction as and at the same rate as the direction and rate of ground-water flow. In a small, well-bounded system, it may be expeditious to assume for the "worst case" analysis that all ground water will eventually have the same quality as the contaminant source. However, more realistic methods involving more complex analyses can be applied to include dispersive and attenuative effects in the aquifer, ~~the~~^{the} following approaches will be considered on a site by site basis.

- a Relatively simple models which include dilution-type processes, e.g., mixing cell models (Bear, 1979), may be appropriate for some sites, especially in view of the fundamental difficulties associated with making measurements of dispersive and attenuative properties for input to models.
- a Analytical models of contaminant transport which have been developed by the Nuclear Regulatory Commission (Codell et al., 1982) and others (Prakash, 1982).
- a Numerical models of contaminant transport including advection and dispersion can be used and have been previously applied to inactive sites, e.g., the Riverton site (Narasimhan et al., 1984).

- c Two step geochemical and hydrologic modeling to incorporate geochemical retardation factors into the contaminant transport calculations. This method will allow chemical interactions between the contaminated ground water and the aquifer sediment to affect the downgradient concentrations of contaminants. Data on the attenuative capacity of the sediment will be used to develop the model.

In general, methods of describing contaminant transport will be chosen which are appropriate for the given hydrogeologic setting the available data, and the level of concern regarding public health and safety. At a processing site, the existing contaminant plume will be considered the best indicator of the dispersive and attenuative properties of the aquifer. Input parameters for models will be derived as realistically as possible based on dimensions of the relative concentrations of contaminants within the plume. Predicted concentrations will be given as a range of values rather than single values.

3.3.3 Impact on beneficial use

For each geohydrologic unit in which elevated concentrations of contaminants related to uranium mill processing are detected, DOE will evaluate the potential impacts on present and future use of the ground water. The present state and EPA standards for drinking water and other use classifications will be used as a

basis for evaluating the degree of contamination and the need for remedial or protective actions for ground-water supplies. Table 2 lists drinking water standards set by the EPA (40 CFR 141 and 40 CFR 143) and states which have UMTRA Project sites.

Water quality standards of primary interest are those issued for waters classified for use as a source of domestic water supply (i.e., drinking water). These standards will be compared with contaminant concentration levels in order to qualitatively evaluate the potential health impacts. Maximum concentrations set as allowable limits for other use classifications also are considered. These include limits established for waters used for contact and non-contact recreation, industrial, municipal, and agricultural purposes, and to support aquatic organisms and other wildlife. Where a discrepancy between limits set for different use classifications is found, the lowest, most conservative limit is considered. For states where no distinction between surface and ground water is made, water quality standards for surface water are accepted (EPA, 1976). For key contaminants without legislated water quality ~~Table 2~~ standards (e.g., uranium, molybdenum), water quality criteria currently under consideration by the EPA, U.S. Department of Health, state health departments or those established by a widely recognized authority will be considered.

Evaluating the availability of alternate supplies of water will include presently used alternate supplies, presently

Table 2

Table 2 Drinking Water Quality Standards

[illegible]

三

Inorganic chemical (mg/l)	EPA Primary	EPA Secondary	AZ	CO	ID	NM	ND	OR	TX	UT	WY
Ra-226 & Ra-228	5	--	5	5	5	30	5	5	5	5	5
Gross alpha ^c	15	--	15	15	15	15	15	15	15	15	15
Beta particle & photon radio- activity from man-made radio- nuclides ^d	Average annual conc. shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem.										
Uranium,	--	--	--	80	--	--	--	--	--	--	--
Cesium 134	--	--	--	15	--	--	--	--	--	--	--
Plutonium-238	--	--	--	60	--	--	--	--	--	--	--
239, & 240	--	--	--	20,000	--	--	--	--	--	--	--
Thorium-230 & 232	--	--	--	80	--	--	--	--	--	--	--
Tritium	--	--	--	80	--	--	--	--	--	--	--
Gross Beta	--	--	--	--	--	--	--	--	--	--	--
Iodine-131	--	--	--	--	--	--	--	--	--	--	--
Strontium-90	--	--	--	--	--	--	--	--	--	--	--
Organic chemicals in micrograms/l (ug/l)											
Endrin	0.2	--	0.2	0.2	0.2	repeat	0.2	--	0.2	0.2	--
Lindane	4.0	--	4.0	4.0	4.0	repeat	4.0	--	4	4	--
Methoxychlor	100.	--	100.	100.	100.	repeat	100.	--	100	100	--
Toxaphene	5	--	5	5	5	repeat	5	--	5	5	--
2, 4-D	100.00	--	100.	100.	100.	repeat	100.	--	100	100	--
2,4,5-TP	10.	--	10.	10.	10.	repeat	10.	--	10	10	--
Trihalomethanes ^f	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Trichloroethylene (TCE)	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Carbon Tetrachloride	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
1,2-Dichloroethane	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Benzene	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Tetrachloroethylene	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
1,1-dichloroethylene	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Polychlorinated	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Biphenyls (PCBs)	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Toluene	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--
Phenols	100.0	--	100.0	100.0	100.0	repeat	100.0	--	100.0	100.0	--

Table 2, cont.

Proposed maximum containment levels in micrograms/l (ug/l)

Note: The following proposed MCLs for the volatile organic compounds are likely to become MCLs in the near future (personal communication, ^{Pardee} ~~June~~ 1985).

~~Pardee, EPA in Dallas.~~

	EPA Primary (Proposed)
Trichloroethylene (TCE)	5
Carbon Tetrachloride	5
Vinyl chloride	1
1,2-Dichloroethane	5
Benzene	5
Tetrachloroethylene	10
1,1-dichloroethane ylene	7
1,1,1-Trichloroethane	200
P-Dichlorobenzene	750

Microbiological

Coliform bacteria: see 40 CFR 141 (applies to surface and ground waters)

Turbidity: ^R Applies to surface water for community systems, see 40 CFR 141.

^R ~~Notes:~~ The Federal water quality standards are covered in the EPA's National Interim Primary (40 CFR 141) and secondary (40 CFR 143) Drinking Water Regulations. Most of the states have adopted these regulations in their state rules with little modification. 40 CFR 141 and 40 CFR 143, revised as July 1, 1984. Primary and secondary standards are listed separately under EPA headings but are listed together for the states merely for convenience.

EPA: ^{3a} When the annual average of the maximum daily air temperatures for the location in which the community water system is situated is the following, the MCLs for fluoride are:

Temperature Degree Fahrenheit	Temperature Degree Celsius	Level mg/l
53.7 and below	12.0 and below	2.4
53.8 to 63.8	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

^D Nitrate levels not to exceed 20 mg/l may be allowed in a non-community water system if the supplier of water at the discretion of the State. See 40 CFR 141 for details.

^C Gross alpha particle activity includes radium-226 but excludes radon and uranium.

^D Details are given in 40 CFR 141.26 concerning compliance if gross beta is less than 50 pCi/l.

Note that this regulation applies to man-made radioactivity, which are not expected at UMTRA sites.

^eHealth advisory for uranium by the EPA is 10 pCi/l (0.37 Bq/l) for chronic exposure.

^fTotal trihalomethanes is the sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane (bromoform) and trichloromethane (chloroform).

Arizona: The column lists drinking water standards (Arizona R9-8-221E). Standards for surface water for domestic use are not listed above and are found in Arizona R9-21. In July, the Arizona Water Quality Standards will be updated, call 602-257-2352 or 255-4285. The MCLs apply to community water systems.

Colorado: See CO regulation 3.11.5 for allowable increase in TDS. *The standards for Cesium-134, Plutonium, Thorium, and Tritium are proposed standards for subsurface waters, not for public water systems. Allowable increases in TDS are also in proposed regulations.*

New Mexico: Standards for ground water of 10,000 mg/l TDS or less. Standards for mercury and organic compounds apply to total unfiltered concentrations of the contaminants (p. 21 NM WQCC, 1982). Standards for irrigation use include standards for domestic water plus standards in mg/l for Al, ~~S~~, Bo 0.75, Co 0.05, Mo 1.0, and Ni 0.2.

Oregon: The primary and secondary contaminants are listed in one column. The primary contaminants are the same as the EPA's and the other contaminants are secondary.

Texas: The primary and secondary contaminants are listed in one column. The primary contaminants are the same as the EPA's and the other contaminants are secondary.

Utah: The MCLs above are for community water systems. See the regulations for non-community systems. Primary standards are for the protection of human health and must be met by all public drinking water systems. Secondary regulations provide guidance in evaluating the esthetic quality of drinking water and should be met to avoid consumer complaint. No MCL has been established for sodium. However, sodium must be monitored and reported.

↑
If the sulfate level of a community water system is greater than 500 mg/l, the supplier must satisfactorily demonstrate that no better quality water is available, and the water shall not be available for human consumption from commercial establishments. In no case shall the committee allow the use of water having a sulfate level greater than 1000 mg/l. If TDS is greater than 1000 mg/l, the supplier shall satisfactorily demonstrate to the committee that no better water is available. The committee shall not allow the use of an inferior source of water if a better source of water (i.e., lower in TDS) is available.

Wyoming: Wyoming classifies its ground waters for domestic, agriculture, and livestock use. The limits in the table are all for domestic use and Wyoming does not have primary and secondary standards, i.e., the limits are all primary.

Glossary to Table 2

Definitions (after 40 CFR 141 and 40 CFR 143): These defined terms are used in Table 2 explanation below. Community water system - a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. Contaminant - any physical, chemical, biological, or radiological substance or matter in water.

Maximum contaminant level (MCL) - the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system.

Non-community water system - a public water system that is not a community water system.

Public water system - A public water system is either a community water system or a non-community water system.

Secondary maximum contaminant levels (SMCLs) - the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of public water system... and which, in the judgement of the (EPA) Administrator, are requisite to protect the public welfare.

available but unused supplies, and supplies not presently available but which could be developed.

The present value of contaminated water supplies will be determined through a combination of interaction with state agencies and/or local water companies and a field determination of the nature and extent of contamination. The proximity, withdrawal rates, uses and sources of presently used water will be found in the records of state, county and municipal water administration offices, and may be supplemented by a field survey of the area surrounding the site to gather information on undocumented water users. ⁴ The future water value and predicted uses will be developed through consultation ^{with} ~~of~~ a water resource economist with Federal, state, county and local planning commissions. Projections of future water use will be qualified by the accuracy of the assumptions used in the projection. Most projection methods assume continuations of past conditions, present conditions or in historical trends. The two factors of primary concern to water use planners are changes in agricultural productivity and population. The period of accuracy of demographic projection techniques (e.g., cohort-component modeling) is typically limited to 30 years (Pittenger, 1976). Although the rules and regulations guiding the UMTRA Project require stabilization of the contaminated materials for 1000 years or at least 200 years, it is felt that water use and resource value projections beyond 50 years are of limited usefulness.

3.3.4 Control alternatives

EPA's draft ground water strategy provides for mitigating contamination of aquifers that are current or potential sources of drinking water. The two basic approaches to mitigation include ground water protection and aquifer restoration. The former involves technologies that will preclude the spread of existing contamination within an aquifer, while the latter requires physical removal and treatment of contaminated ground water coupled with re-injection of the treated water. ^{CLEAN-UP} ~~Cleanup~~ policy will vary, depending on site-specific circumstances. ~~however, the agency is leaning toward aquifer restoration where ground water may even be potentially usable.~~

Aquifer restoration (removal and treatment) is generally very costly in comparison to ground water protection techniques (physical containment). In keeping with EPA policy, both options should be considered for any site. Criteria for selecting an optimum ^{CLEAN-UP} ~~cleanup~~ approach include technical feasibility, effectiveness and cost. EPA has no quantitative guidelines for evaluating cost versus benefit; thus decisions must be made on a case-by-case basis.

From a technical standpoint, three factors govern the feasibility, effectiveness and costs of aquifer restoration. These are the volume of contaminated ground water, its removeability and its treatability. Where a vast volume of ground water is contaminated, or where an aquifer is hydraulically connected to a

surface water body, it may neither be technically or economically feasible to pump, treat and recharge. Similarly, in a situation where an aquifer is thin, discontinuous, heterogeneous, or of low permeability, aquifer restoration may not be feasible. Finally, while it may be technically and economically feasible to collect contaminated ground water, it is possible that the type and/or levels of contamination may not be feasible treatable. These factors must all be considered in selecting either a ground water protection or aquifer restoration technology.

3.3.4.1 Aquifer protection alternatives

Once the need for remedial measures or actions to protect the water resources at a site have been established, the following steps will be initiated:

- a Develop a list of potential protective/restoration alternatives.
- a Evaluate the technical feasibility of the alternatives.
- a Perform a cost-benefit analysis of the alternatives.

The technical feasibility of a wide range of possible actions to protect the ground water resource

will be considered for each site. Some of these options are listed in Table 3. The following sections present more detailed information on selected protective alternatives that will be considered by the UMTRA team.

Section left out, see attachment

Physical containment

In protecting an aquifer, a remedial action that should be evaluated is physical containment, or isolation, of either the contaminant source or the contaminated ground water. Physical containment is accomplished through installation of an impermeable boundary between containment and clean portions of an aquifer. Physical containment technologies include: slurry walls; grout curtains; and sheet piling.

Slurry walls

Description

Installation of slurry walls involves excavating a trench through or under a slurry of bentonite clay and water, then backfilling the trench with the original soil (with or without the bentonite mixed in). The trench is usually excavated down to an impervious barrier to eliminate ground water under flow. During the excavation

Insert G:

The following sections present more detailed information ~~on~~ on selected protective alternatives that ~~will~~^{pages} be considered by the UMTRA_{Project} team.

Physical Containment

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Table 3 Potential Actions to Protect Water Resources

Stabilization of tailings in place or on-site:

- Stabilize and cover with low permeability sediment . . . (e.g., clay).
- Construct diversion structures or drains to intercept surface and shallow ground water.
- Construct slurry walls/grout curtains (physical containment).
- Move tailings locally onto a low-permeability sediment layer with capillary breaks.

Move to alternate site:

- Stabilize and cover with low-permeability sediment.
 - Construct low-permeability sediment under layer/capillary breaks.
-

process, the trench walls are supported by the slurry, preventing the walls from slumping or caving in, and eliminating the need for additional shoring materials. Most importantly, the process is designed to force the bentonite slurry through its own weight, into the more permeable surrounding soils, forming a filter cake of low permeability which lines the walls and bottom of the trench.

Application

The application of slurry walls as impermeable barriers is limited to areas where materials are trenchable and have sufficient permeability to form a filter cake. Additionally, trenching equipment's capabilities. Thus, this technology is practical only when ground water contamination exists fairly near the surface. Further, as part of the remedial action process, tests must be performed to determine whether the slurry could be affected by chemical reaction with the contaminants, thus rendering it unsuitable for application.

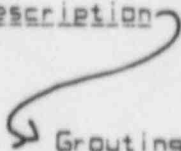
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Cost considerations

Installation of slurry walls is costly due to the small number of specialty firms currently experienced in their construction, however, in comparison with other containment technologies (grout curtains, sheet piling), this technology is proving more economically feasible, and where applicable, more effective. While this technology requires expensive geo-technical, hydrologic and laboratory tests to determine wall efficiency, such costs must be evaluated in terms of the technology's capabilities to ensure long-term protection (a life expectancy of many decades) requiring little or no maintenance.

Grout curtains

Description



Grouting is the pressure injection of special fluids into a rock or soil body. The fluids set or gel in the voids in the rock and, when carried out in the proper pattern and sequence, the process forms a wall or curtain that is an effective ground water barrier.

Application

→ Due to the high cost of installing grout curtains, they are usually used only to seal voids in porous or fractured rock where other methods to control ground water are technically unfeasible.

Cost constructions

→ Grout curtains are on the order of three times as costly as slurry walls. The high cost of this technology is, in part, due to the limited number of firms conducting grouting and also because the technique is as much an art as a science. The specialized equipment needed, the extensive testing, and the cost of the grout itself all increase the expense.

Sheet piling

Description

→ The construction of a sheet piling cut off wall involves driving interlocking piles into the ground with a pneumatic or steam pile driver. When first placed in the ground, the sheet piling cut off allows easy water flow through the edge interlocks. However, with time,

fine soil particles fill the seams and an effective barrier is realized. The performance life of the sheet piling cut off walls can vary between seven and 40 years.

Application

→ Sheet piling could be most feasible in situations where the water table is near surface, a confining layer exists at a reasonable depth, and surficial materials are fine-grained to allow ease in driving the sheet metal. Sheet piling is not feasible for use in very rocky soils.

Cost

→ Economic advantages of this method are the relative ease of installation, readily available materials, low maintenance, and relatively low cost. Disadvantages include the fact that they cannot be used in rocky soils, the wall is initially not waterproof, and the piling may be susceptible to corrosive chemicals.

*Continue with
type*

3.3.4.2 Restoration of ground water

In addition to the options in Section 3.3.4.1, DOE will evaluate the feasibility of aquifer restoration and providing alternative sources of water for existing or future uses. Specific aquifer restoration and treatment alternatives to be considered by DOE are summarized in the following sections.

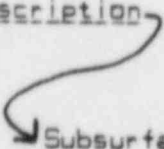
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Collection Systems

While previous sections have addressed ground water protection alternatives, aquifer restoration techniques must be evaluated for sites where ground water is currently or potentially usable. The first phase of aquifer restoration requires withdrawal of contaminated ground water from the aquifer. Systems for collection of ground water are described below.

Subsurface drains

Description



Subsurface drains consist of underground gravel-filled trenches often lined with tile or perforated pipe designed to intercept leachate or infiltrating water and transport it away from the wastes

to a suitable point for treatment and/or disposal. Subsurface drains can be used in any clay or silty clay soil where the natural permeability is insufficient to maintain sufficient flow. In this situation the subsurface drain provides an area of higher permeability to channel near surface waters or leachates to the desired collection point.

Application

These systems are generally constructed by excavating a trench, laying perforated pipe or tile along the bottom, and backfilling with a permeable gravel which is covered by a fabric liner and clay to prevent fine materials from clogging the drain. This procedure is confined to situations where the contaminated ground water is at a depth consistent with the trenching equipment's capabilities. Advantages of this type of system include low operating costs since flow is by gravity, considerable flexibility in design and spacing, and fairly good reliability providing that monitoring is provided.

Cost consideration

✓ Costs for subsurface drains are relatively low.

Ground-water pumping

Description

Ground-water pumping is employed to actively divert ground water near a disposal site and is effective in any porous or fractured medium. This technology may be employed to lower a water table, in order to contain a contaminant plume, or collect the ground water for treatment.

*
depends how
fractured?

Application

✓ Pumping to lower a water table may be appropriate under several conditions such as: 1) lowering the water table in an unconfined aquifer so that contaminated ground water does not discharge to a hydraulically connected receiving stream; 2) lowering the water table so that it is not in direct contact with the waste; or 3)

~~lowering the water table so that it is not in direct contact with the waste~~ or 3) lowering the water table to prevent contamination of an underlying leaky aquifer.

(3) repeats
(2)?

How about recharge - pumping barrier to control ground water contaminant migration?

Cost considerations

For cost comparisons, examples for two applications are provided. One method for lowering the water table is to use a wellpoint system, a series of closely spaced wells usually connected by a header pipe. Costs can vary widely depending on site conditions.

Advantages are high design flexibility, lower construction costs than ground water barriers, and high reliability with proper monitoring. Disadvantages are high operation and maintenance costs as compared to ground water barriers.

Although well point systems can be suitable for extracting a plume in some cases, generally, high capacity wells are needed. The number of wells and pumps needed to contain a plume are determined on a site-by-site basis and are dependent on the radius of influence of the wells.

Physical treatment

Following the collection of contaminated ground water, the next step in aquifer restoration involves

treatment of the water to suitable standards and the eventual reinjection into the aquifer or discharge to the surface water system.

Permeable treatment beds

Description

This technology involves the installation of permeable material in a trench below water table to chemically or physically remove contaminants as ground water passes through. The material used in the beds is dependent on the type of contamination present. Some materials frequently used include: 1) limestone or crushed shell, where neutralization of acidic ground water and/or the removal of certain metals such as cadmium, iron, and chromium, is desired; 2) activated carbon, for removal of organic compounds; and 3) Glauconitic greensands, for adsorption of several heavy metals. Zeolite and synthetic ion exchange resins, which are very effective in removing heavy metal contamination have been explored, but are currently economically and practically unfeasible due to short life, high cost, and re-activation difficulties.

Application

As with slurry walls, permeable treatment beds are applicable only in areas where materials are trenchable and where required trench depths are consistent with the trenching equipment's capabilities. Moreover, permeable treatment beds are only a temporary measure, since bed material must be replaced periodically as the material becomes contaminated. In addition, at present, only a limited number of contaminants can be treated. In short, for this method, the current state-of-the-art is more or less conceptual.

Cost considerations

Estimated costs for construction of a permeable treatment bed include the cost of trench excavation and dewatering, trench shoring, bed materials, and bed installation. Bed materials is the factor that bears most heavily on cost.

Treatment technologies

A variety of methods have been successfully employed in treating ground water contaminated with uranium, metals, sulfate and dissolved solids. Water treatment

and uranium removal technology are addressed in outline line form in the following sections.

Water treatment

1. Description

- a. Modular units used in conjunction with aquifer pumping system.

2. Flow equilization

- a. Dampens flow fluctuations and concentration fluctuations
- b. Used in conjunction with additional treatment; carbon adsorption; biological treatment; ion exchange.

3. Precipitation; flocculation and sedimentation

- a. Removes substance by precipitation; flocculation and sedimentation separately or in series.
- b. Good for heavy metals: cadmium, lead, arsenic, chromium.

c. Sludges may be environmental hazard.

d. Usually requires flow 1000 gpd.

e. Process is often incomplete.

4. Biological treatment

a. Primarily geared to organic chemicals.

b. Highly variable process dependent on type of contaminant.

c. Costs are highly variable depending on exact treatment method.

5. Carbon adsorption

a. Primarily for organics, but can remove some inorganics.

b. Can remove with varying degrees of success: arsenic, vanadium, cadmium, selenium, molybdenum.

c. Requires low suspended solids, concentrations less than 1000 ppm.

6. Ion exchange

- a. Uses synthetic resins to effect exchange.
- b. Can be used to remove soluble metals:
molybdenum.
- c. Not suitable for high concentrations.
- d. Spent regenerant may be left highly contaminated.
- e. Costs are highly variable, dependent on resin and regenerant needs. Overall, costs are quite high.

7. Liquid ion exchange

- a. Similar to resins, instead uses aqueous soln.
- b. Can remove all soluble cations in theory.
- c. Can remove heavy ^{polyvalent}~~divalent~~ metals, in practice.
- d. Can handle higher concentrations than resins.
- e. Regenerant will contain high concentration of contaminants.
- f. Cost competitive with resins.

Uranium removal techniques

Alkaline earth water softeners

1. Lime $(\text{Ca}(\text{OH})_2)$ and Lime-Soda $(\text{Ca}(\text{OH})_2)$ and Mg CO_3
2. NaOH
 - a. Has been used to remove U from seawater.
 - b. Process is not well understood.

Coagulants

1. Aluminium sulfate, $\text{Al}_2 (\text{SO}_4)_3$
Ferric sulfate $\text{Fe}_2 (\text{SO}_4)_3$
Ferrous sulfate Fe SO_4
are most common coagulants

Adsorption

1. Titanium oxide and activated charcoal used.
 - a. Useful if carbonate concentrations are low.

Ion exchange (resins)

1. Effective for uranyl carbonates and vanadium.
2. Must be very carefully controlled.

Reverse osmosis

1. Uses cellulose acetate membrane.
2. Effective for uranium sulfate but not as good as ion exchange resins.

3.3.4.3 Selection of control alternatives

Cost-benefit analyses of all reasonable technical approaches, will be performed to aid in the ranking and selection of an appropriate alternative. The objectives of the analyses will be to provide comparisons of approximate costs of the different control and aquifer restoration alternatives relative to the value of the water resource. Estimates of individual cost elements may be obtained from sources such as vendor quotations, contractor bids, published information, and in-house data. Where necessary, cost elements can be adjusted to a common date by means of standard cost indexes such as the Handy-Whitman index or Engineering News-Record

construction cost indexes. In general, costs will be classified as either capital or operation and maintenance costs.

Included in the benefits considered for a proposed remedial action, will be a qualitative discussion of the potential for reducing adverse health impacts of the water contamination. A strategy for minimizing health impacts may include provisions for land purchase by DOE, establishment of deed restrictions for water use, installing well-head treatment devices, and reliance on long-term regulatory controls of other kinds to restrict access to the contaminated water resource.

delete

Assuming that an acceptable method of evaluating potential resource damages could be agreed upon, DOE may consider various options of minimal protective actions coupled with monetary compensation to local populations could decide how they would wish to use compensation funds. Such options would provide greater flexibility in dealing with the uncertainties of future water use, water valuation, and changes in technical capabilities.

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