RESTORING GROUND WATER QUALITY FOLLOWING IN SITU LEACHING

by

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ABSTRACT

To assist mining companies in planning for restoration of ground water quality following in situ uranium leaching, the Bureau of Mines funded the preparation of two reports. "Restoration of Groundwater Quality After In Situ Uranium Leaching" primarily describes options for disposing of the waste solution from restoration and provides engineering cost estimates. "Analysis of Groundwater Criteria and Recent Restoration Attempts After In Situ Uranium Leaching" summarizes restoration attempts, presents an empirical equation predicting the amount of ground water flushing required, and presents State and Federal permit requirements. This paper summarizes some of the information from those reports.

INTRODUCTION

When planning in situ uranium leaching, the restoration of groundwater quality is one of the areas of greatest uncertainty. To assist mining companies in such planning, the Bureau of Mines has funded the preparation of two reports.

The first report was completed in 1979 by Ford, Bacon, and Davis Utah, Inc., and is titled "Restoration of Groundwater Quality After In Situ Uranium Leaching." It primarily describes the various options for dealing with the large volumes of waste solution from restoration and presents engineering cost estimates. It also describes related geology, geochemistry, regulations, and several restoration attempts.

The second report was completed in 1981 by Resource Engineering and Development, Inc., and is titled "Analysis of Groundwater Criteria and Recent Restoration Attempts After In Situ Uranium Leaching." Volume I contains summaries of restoration attempts within the last 5 years, capital costs of disposal systems reported by operators, and an empirical equation that provides a guide as to the amount of ground water flushing required to meet restoration criteria. Volume II contains in situ leaching permit requirements, including restoration requirements, for Texas, Wyoming, New Mexico, Utah, Montana, Colorado, and South Dakota, and Federal requirements.

This paper summarizes some of the information in those reports. Those who want the complete contract reports should contact Daryl Tweeton at the Bureau of Mines in Minneapolis, Minn., 612-725-3468.

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DISPOSAL METHODS

The waste solution from in situ leaching and from postleach restoration can be disposed of in either a deep disposal well or an evaporation pond. Generally, deep disposal wells have been used in Texas and evaporation ponds in Wyoming.

Deep-Well Disposal

Injection of waste through a deep well into a zone that does not contain useful water offers the advantage that the waste is completely removed from the biosphere. Examples of disposal of waste solutions similar to that from an in situ leaching operation occur in a report on uranium mills in New Mexico[2] and in Union Carbide's permit for the Palangana Dome uranium plant.[3]

A deep-well disposal system includes equipment required to concentrate and condition the waste stream for injection and to transport the waste solution from the mining site to the injection well. Deep-well disposal is limited to waste solutions that will not plug the injection zone by the precipitation of solids in reactions between the solution and the matrix of the host aquifer. In some cases, precipitation can be prevented or reduced by adjusting pH or adding retardants such as sodium hexametaphosphate for calcium sulfate.

Summaries of the capital and operating costs are presented in tables 1 and 2. Capital costs are calculated for variations of each of the primary factors affecting a disposal well: injection rate, well depth, and drilling difficulty. The operating cost estimate is divided into the direct costs of power, chemicals, and operating and maintenance, and a concluding summary of operating costs that includes overhead expenses and fixed charges. Power costs are calculated for an average wellhead pressure of 260 psi. Chemical costs include acid for pH adjustment, polyphosphate to retard calcium sulfate deposition in the injection zone, and copper sulfate to control bacteria and fungi. Chemical additions are proportional to flow rate.

TABLE 1. - Deep-well disposal capital costs versus well depth and rock type, mid-1978 dollars

	Well capacity	
	200,000 gpd (single well)	1 million gpd (2 wells at 500,000 gpd each)
5,000-ft well depth:		
Average rock.......	1,202,000	3,485,000
Difficult rock.....	1,345,000	3,761,000
10,000-ft well depth:		
Average rock.......	1,538,000	4,148,000
Difficult rock.....	2,083,000	5,220,000
15,000-ft well depth:		
Average rock.......	2,001,000	5,069,000
Difficult rock.....	3,200,000	7,440,000

[2] Lynn, R. D., and Z. E. Arlin. Anaconda Successfully Disposes Uranium Mill Waste Water by Deep Well Injection. Min. Eng., v. 14, July 1962, pp. 49-52.
[3] Union Carbide Corp. Permit for Subsurface Disposal of Industrial Waste, No. WDW-134. Texas Water Quality Board, Austin, Tex., Sept. 22, 1976.

TABLE 2. - Operating costs for deep-well disposal system

(5,000-ft well of average drilling difficulty)

	Capacity			
	200,000 gpd		1 million gpd	
	Cost per 1,000 gal[1]	Pct of total	Cost per 1,000 gal[1]	Pct of total
Direct costs:				
Power (injection pump, transfer pumps, ancillary loads)............	$0.13	3	$0.13	5
Chemicals:				
pH adjustment......................	.33	8	.33	13
Sodium hexametaphosphate..........	.06	2	.06	2
Copper sulfate....................	.01	Neg	.01	Neg
Operating and maintenance:				
Operating labor....................	.09	2	.04	2
Operating supervision (15 pct of OL)............................	.01	Neg	.01	Neg
Maintenance and repairs (1 pct of TCI)...........................	.20	5	.12	5
Laboratory charges (10 pct of OL).	.01	Neg	Neg	Neg
Total direct costs...........	.84	21	.70	28
Overhead costs:				
Plant overhead (60 pct of O&M)......	.19	5	.10	4
Administrative (15 pct of O&M)......	.05	1	.03	1
Total overhead...............	.24	6	.13	5
Total direct and overhead costs......................	1.08	27	.83	33
Fixed charges:				
Sinking fund payment (8 pct, 10-yr life)............................	1.38	35	.80	32
Interest (10 pct, 50-50 debt-equity)	1.00	25	.58	23
Insurance, taxes, miscellaneous (2.5 pct).......................	.50	13	.29	12
Total fixed charges..........	2.88	73	1.67	67
Total operating costs........	3.96	100	2.50	100

Neg Negligible.
OL Operating labor.
O&M Operating and maintenance.
TCI Total capital investment.
[1]Mid-1978 dollars.

Solar Evaporation Ponds

The liquid waste from the leaching operation or from surface treatment facilities can be evaporated in a shallow pond with a large surface area. As evaporation occurs a sludge remains, which is an important disadvantage because there are stringent regulations governing the disposal of the sludge.

Summaries of capital and operating costs for solar evaporation are listed in tables 3 and 4. The cost for disposing of the sludge at the pond site by backfilling and sealing is included in the estimate. To estimate costs appropriate for in situ leaching, an initial grade of 1 percent and a pond lining of 10-mil PVC are assumed. Costs change for variation of feed capacity, net evaporation rate at the site, grade, and lining. (The contract report discusses available linings.) The fixed charges dominate, as would be expected for systems requiring extensive excavation and little operating labor. Expenses are roughly inversely proportional to the net evaporation rate.

TABLE 3. - Total capital investment for solar evaporation ponds, mid-1978 dollars

Net evaporation rate, in/yr	Pond system capacity	
	200,000 gpd	1 million gpd
40	3,010,000	15,148,000
30	4,018,000	20,221,000
20	6,037,000	30,380,000
10	12,108,000	60,929,000

TABLE 4. - Operating costs for solar evaporation pond system at 40-in/yr net evaporation rate

	Pond system capacity			
	200,000 gpd		1 million gpd	
	Cost per 1,000 gal[1]	Pct of total	Cost per 1,000 gal[1]	Pct of total
Direct costs:				
Power (pumps and ancillary loads)	$0.03	Neg	$0.03	Neg
Chemicals	0	0	0	0
Operating and maintenance:				
Operating labor	.03	Neg	.01	Neg
Operating supervision (15 pct of OL)	Neg	Neg	Neg	Neg
Maintenance and repairs (0.25 pct of TCI)	.10	2	.10	2
Laboratory charges (10 pct of OL)	Neg	Neg	Neg	Neg
Total direct costs	.16	3	.14	2
Overhead costs:				
Plant overhead (60 pct of O&M)	.10	1	.09	1
Administration (15 pct of O&M)	.03	Neg	.02	Neg
Total overhead costs	.13	2	.11	1
Total direct and overhead costs	.29	4	.25	4
Fixed charges:				
Sinking fund payment (8 pct, 10-yr life)	2.85	46	2.75	46
Interest (10 pct, 50-50 debt-equity)	2.06	33	1.99	33
Insurance, taxes, miscellaneous (2.5 pct)	1.03	17	.99	17
Total fixed charges	5.94	96	5.73	96
Total operating costs	6.23	100	5.98	100

Neg Negligible.
OL Operating labor.
O&M Operating and maintenance.
TCI Total capital investment.
[1]Mid-1978 dollars.

SURFACE TREATMENT

The waste stream from leaching or from restoration can be sent directly to the disposal system (well or pond), or it can first be treated to produce two streams. One stream is purified water, and the other is a more concentrated brine carrying most of the dissolved solids. The advantages of the second method are that the purified water can be reused, thereby reducing the total consumption of water, and the disposal system does not need as large a capacity to receive the concentrated brine as to receive the total waste stream.

The surface treatment technique that has been used by in situ leaching companies is reverse osmosis. Other treatment methods that are potentially useful are described.

Reverse Osmosis

Reverse osmosis is a physical means of separating dissolved ions from an aqueous stream. An externally applied pressure in excess of the solution's inherent osmotic pressure forces water through a semipermeable membrane while the dissolved ions are rejected. A solution's inherent osmotic pressure is a function of the type of constituents, the ionic characteristics of the dissolved solids, and the relative and absolute concentrations of the solutes. A useful rule of thumb for in situ leaching solutions is that 1,000 mg/l dissolved ions requires approximately 10 psi of applied pressure.

Tables 5 and 6 summarize capital and operating costs, based on actual field systems and experience, as of mid-1978. The sizes of the field systems range from 10,000 to 1 million gpd. These reverse osmosis units incorporate a flexible mechanical design to maximize water recovery, pertinent instrumentation to monitor water quality and flow, a design to minimize membrane fouling and scaling, and a membrane cleaning system. These units are skid mounted and require only power and piping hookups. These prices do not include site engineering fees or freight costs. The operating costs include power, operation, maintenance, and chemicals. The cost assumptions are power at 2.5 cents per kilowatt-hour, membrane replacements required at a rate of 50 percent per 3 years, and a maintenance requirement from past experience. The estimate is based on labor and supervision for round-the-clock and round-the-week operation, with the reverse osmosis unit set up and producing at full capacity for 300 days per year.

TABLE 5. - Capital costs for reverse osmosis system, mid-1978 dollars

	Capacity (feed rate)	
	200,000 gpd	1 million gpd
Direct costs:		
Equipment unit[1] (membrane assembly, high-pressure pump, basic instrumentation...........	139,000	597,000
Peripheral equipment[1] (prefilters, surge tank, holding tank, water quality and flow instrumentation, pH control system, transfer pumps, piping, valves................................	97,000	358,000
Other direct costs (20 pct of equipment): Delivery costs, installation costs, site improvements, electrical hookups, miscellaneous........	47,000	191,000
Total direct costs........................	283,000	1,147,000
Indirect costs (5 pct of direct costs): Engineering and supervision, construction expenses........	14,000	57,000
Total direct and indirect costs...........	297,000	1,204,000
Contractor's fees (2 pct).........................	6,000	24,000
Total capital investment..................	303,000	1,228,000

[1]Basic cost data for equipment provided by L. J. Kosarek, Director of Systems Engineering Research and Development, El Paso Environmental Systems, El Paso, Tex. To convert basic data for product-water capacity to feedwater capacity, an operation with 85-pct water recovery is assumed.

TABLE 6. - Operating costs for reverse osmosis treatment

	Capacity (feed rate)			
	200,000 gpd		1 million gpd	
	Cost per 1,000 gal[1]	Pct of total	Cost per 1,000 gal[1]	Pct of total
Direct costs:				
Power:				
Feed pump power	$0.13	11	$0.13	13
Ancillary (10 pct at feed pump): Transfer pumps, booster pumps, chemical feeders, instrumentation, and lighting	.01	1	.01	1
Chemicals	.06	5	.06	6
Operating and maintenance:				
Operating labor	.02	2	Neg	Neg
Operating supervision (25 pct of OL)	Neg	Neg	Neg	Neg
Maintenance material and labor[2] (includes membrane replacement)	.11	9	.11	11
Total direct costs	.33	28	.31	31
Overhead costs:				
Plant overhead costs (60 pct of O&M)	.11	9	.08	8
Administrative costs (15 pct of O&M)	.03	2	.02	2
Total overhead costs	.14	11	.10	10
Total direct and overhead costs	.47	39	.41	41
Fixed charges:				
Sinking fund payment (8 pct, 10-yr life)	.35	29	.28	28
Interest (10 pct, 50-50 debt-equity)	.25	21	.20	20
Insurance, taxes, miscellaneous (2.5 pct)	.13	11	.10	10
Total fixed charges	.73	61	.58	58
Total operating costs	1.20	100	.99	100

Neg Negligible.
OL Operating labor.
O&M Operating and maintenance.
[1]Mid-1978 dollars.
[2]Evaluated from information provided by L. J. Kosarek, Director of Systems, Engineering Research and Development, El Paso Environmental Systems, El Paso, Tex.

Other Treatment Methods

Other methods that are described in the contract report include electrodialysis, distillation, ion exchange, foam separation, and freeze separation.

Electrodialysis can be viewed as a combination of reverse osmosis and ion exchange. Ions pass through semipermeable membranes under the influence of an electric field. In a typical design, membranes, spacers, and electrodes are stacked and held together by end plates much like a plate and frame filter. Spacing is usually about 0.1 inch, and spacers are arranged to provide a tortuous flow path. Stacks range from 0.5 to 2,400 square meters of membrane area. A large stock can desalt 150 gpm at 20- to 50-percent salt removal. Practical systems use two to six stages. Electrodialysis is more expensive than reverse osmosis. A cost estimate from a supplier of electrodialysis equipment indicated a total operating cost of $2 to $3 per 1,000 gallons.

Distillation appears to be prohibitively expensive, four to five times the cost of reverse osmosis. The high cost is partly due to the high energy requirements. Similarly, ion-exchange treatment costs two to five times as much as reverse osmosis.

Water purification by freezing has not been applied to in situ leaching, but the process is claimed to have the potential for low costs, high water recovery, and effective contaminant rejection. The basis of the process is the principle that when ice is frozen from an aqueous solution of salts, the ice is a distinct and purer phase of water. The ice excludes most of the salts from its crystal structure. Costs for freeze separation have been estimated to be 20 to 40 percent greater than costs for reverse osmosis treatment for small flow rates, and potentially 20 to 40 percent less than costs for reverse osmosis for high flow rates.

SUMMARIES OF RESTORATION ATTEMPTS

The results of restoration attempts conducted at five operations in Texas and one in Wyoming (Irigaray) are summarized in table 7, prepared in the summer of 1980. With the exception of the commercial restoration at Intercontinental Energy Corp.'s Pawnee property, these restoration attempts may all be described as relatively small field tests. Several of these companies are, however, preparing for large-scale restoration of their mined-out areas.

TABLE 7. - Summary of restoration attempts

Company	IEC	Mobil	Mobil	WMC	WMC	WMC	WMC
Site	Pawnee	O'Hern	O'Hern	Irigaray	Irigaray	Irigaray	Bruni
Leaching reagents	$NH_3HCO_3 + H_2O_2$	NH_3HCO_3 + oxidant	O_2 + natural HCO_3^-	NH_3HCO_3 + oxidant	NH_3HCO_3 + oxidant	NH_3HCO_3 + oxidant	$NH_3HCO_3 + H_2O_2$
Type of attempt	Mined out area	Field test	Field test	Field test	Field test	Field test	Field test
Area involved	75 by 250 ft	20 by 20 ft	20 by 20 ft	25 by 25 ft	25 by 25 ft	25 by 25 ft	25 by 25 ft
Patterns involved	5	1 with 2 wells	1 with 2 wells	1	1	1	1 with 2 holes
Restoration process used[1]	GWS + RO + spraying	GWS + cation elution	GWS	Clean RO H_2O recycle	Chemical restoration + cation elution.	Cation elution + RO GWS.	Clean H_2O recycle (RO).
Site-specific factors	Shallow deposit, thin deposit, leach chemicals, low clay content.	High clay content	High clay content	High clay content	High clay content	High clay content	High montmorillonite clay content.
Pore volumes used	[1]2	6.2	3.67	0.5	NA	15.2	NA

Restoration levels achieved versus target restoration levels

	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target
NH_3-N, mg/l	167	0.01	88	1.9	NA	NA	105	<1.0	<35	<1.0	33	<1.0	90	1
U_3O_8, mg/l	2.4	2.0	NA	NA	1.8	2.45	5.7	0.098	<2	0.098	1	0.098	9	<0.5
TDS, mg/l	911	903	BB	NA	941	844	NA	NA	NA	NA	NA	NA	NA	NA
Mo^{++}, mg/l	2.8	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cl^-, mg/l	107	250	211	205	202	203	120	10.75	NA	NA	113	10.75	494	623
Ca^{++}, mg/l	80	200	BB	NA	18	8.6	NA	NA	NA	NA	28	(2)	27	105
Conductivity, µmho/cm	1,899	1,310	1,730	1,450	1,586	1,470	1,600	(2)	NA	NA	NA	NA	758	(2)

Company	WMC	WMC	U.S. Steel	U.C.C.	WMC	WMC
Site	Bruni	Irigaray	Clay West	Palangana	Bruni	Irigaray
Leaching reagents	$NH_3HCO_3 + H_2O_2$	NH_3HCO_3 + oxidant	NH_3HCO_3 + oxidant	$NH_3HCO_3 + H_2O_2$	$NH_3HCO_3 + H_2O_2$	$NAHCO_3 + O_2$
Type of attempt	Field test	Field test	Field test	Field test	Field test	Field test
Area involved	25 by 25 ft	25 by 25 ft	0.92 acre[3]	50 by 50 ft	25 by 25 ft	0.8 acre
Patterns involved	1 with 2 holes	1	13	1	1 with 2 holes	11
Restoration process used[1]	Cation elution + strip NH_3	GWS	GWS	GWS	GWS	GWS
Site-specific factors	High montmorillonite clay content.	High-CA clay content	Low and variable permeabilities, normal fault, ground water migration.	Poor permeabilities--clay zones.	High montmorillonite clay content.	High clay content
Pore volumes used	NA	NA	[3]8.4	6.5	NA	[1]5

Restoration levels achieved versus target restoration levels

	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target	Achieved	Target
NH_3-N, mg/l	17	1	123	<1.0	12-71	0.5	16	1.4	300	1	BB	NA
U_3O_8, mg/l	0.5	0.5	12.3	0.098	2-21	0.5	NA	NA	NA	NA	12	0.098
TDS, mg/l	NA	NA	712	793	NA	NA	NA	NA	NA	NA	700	NA
Mo^{++}, mg/l	NA	NA	<0.002	0.0028	3-22	1.0	NA	NA	NA	NA	NA	NA
Cl^-, mg/l	500	623	229.9	10.75	261-770	120-400	NA	NA	600	558-687	BB	NA
Ca^{++}, mg/l	127	105	<0.002	<0.005	NA	NA	NA	NA	80	74-135	BB	NA
Conductivity, µmho/cm	NA	NA	1,950	(2)	NA	NA	1,040	1,200	4,500	2,275-2,693	NA	NA

BB Below baseline.
GWS Ground water sweeping.
NA Not available.
RO Reverse osmosis.
TDS Total dissolved solids.
[1]Restoration ongoing at present time.
[2]Test is ongoing. Final value not available.
[3]Original leach area. Ground water migration caused contaminated area to spread to 3.6 acres.

Several different processes have been used in these restoration attempts. At the Pawnee site, Intercontinental Energy Corp. treated recycled ammonia leach solution aboveground by spraying and reverse osmosis. Mobil Oil Corp. tested several methods at the O'Hern site for flushing the ammonia from clays, including ground water sweeping and cation elution, and also tried a nonammonia leach process. U.S. Steel Corp. has tested ground water sweeping at an old in situ leach pilot plant area at the Clay West property. U.S. Steel's method of disposing of several pore volumes in a deep disposal well and then discharging a treated stream to surface waters appears to have considerable merit. Ground water sweeping was also tested by Union Carbide Corp. in a small test at the Palangana site. Extensive ground water sweeping and cation elution has been done by Wyoming Mineral Corp. at both the Irigaray and the Bruni operations. Wyoming Mineral Corp. was testing ground water sweeping of an ore zone leached with sodium carbonate-bicarbonate and oxygen.

The flushing requirements in table 7 indicate how much ground water displacement is needed to achieve a given degree of restoration at that site. This gives operators an idea of the magnitude of the restoration problem and provides a basis for sizing solution disposal and treatment facilities and for establishing restoration schedules.

The restoration testing indicates that it is extremely difficult, if not economically and technically impossible under existing operating conditions and with present restoration technology, to reduce ammonia and aquifer solutions to the levels set by State regulatory agencies. Complete restoration, as defined by these agencies, may require 50 to 100 pore volumes or more if an ammonia leach process has been used. Each of the three major companies involved in in situ uranium leaching (Mobil, U. S. Steel, and Wyoming Mineral Corp.) has changed or is changing its major operations from ammonia to nonammonia leach solutions.

The nonammonia testing that has been done by Mobil and by Wyoming Mineral Corp. indicates that without the adsorption of ammonia by clays, restoration is faster and more complete than when ammonia is used in leaching. However, it may still be relatively difficult to restore parameters such as uranium, molybdenum, total dissolved salts, and conductivity to the levels set by State regulatory agencies.

Ground water restoration appears to be a bigger problem than was thought earlier. Field testing has shown that "complete restoration," as defined by the State regulatory agencies, has not been attained with reasonable degrees of flushing at any of these sites.

COSTS REPORTED BY OPERATORS

The intent was to obtain the costs of actual restorations and then compare these costs with estimates in the earlier study. However, the available cost information was primarily capital costs of disposal wells and evaporation ponds. Operating costs were not available because the operators had performed little restoration of mined-out areas. They felt that it was too early to accurately estimate operating costs.

The capital costs of several deep disposal wells drilled in Texas during the past few years are shown in table 8. Possible reasons for the large variation in costs follow: Companies having low estimates may not have the same ancilliary pretreatment facilities included in their estimates, corrosion-proof equipment may be used in the case of the higher estimates, and some companies may not include the cost of idle pretreatment equipment that they intend to use. Comparing these costs with the estimates in the earlier study shows that the estimates are consistent with those for the Union Carbide and Wyoming Mineral Corp. wells, and are higher than the others.

TABLE 8. - Disposal well costs reported by in situ leaching operators in Texas

Company	Well depth, ft	Maximum flows per well, gpm	Ancillary equipment cost	Total well cost[1]
Intercontinental Energy Corp..................	4,000	50	NA	$300,000- 350,000
Mobil Oil Corp.........	4,500-5,000	100-150	$150,000	650,000
Union Carbide Corp.....	5,700	100	NA	1,200,000
U.S. Steel Corp........	4,500	200-250	200,000	500,000
Wyoming Mineral Corp. (Lamprecht Site)......	6,000	200	NA	[2]1,100,000

[1]Includes ancillary pretreatment equipment, pumps, ponds, etc.
[2]Does not include cost of ponds.

The capital costs of Wyoming Mineral Corp.'s evaporation ponds are listed in table 9. The estimates in the earlier study indicated that a 200,000-gpd pond capacity with a 35-in/yr evaporation rate costs $2,878,000, or $37,250 per acre. The actual field costs per acre are thus higher in this instance than the estimates.

TABLE 9. - Capital costs for WMC's evaporation ponds in Texas and Wyoming

Site	Pond size, acres	Pond evaporation rate, gpm	Evaporation rate, in/yr	Cost per acre
Bruni....................	3.5	6.3	35	$65,000
Lamprecht................	8.9	16	35	65,000
Irigaray.................	12	36	58	80,000