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TECHNICAL MEMORANDUM

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SUBJECT: Review of SMC By-Product Recovery Proposal
Iron Mountain Mine

PROJECT: SWE69205.04.02

Background

On December 13, 1993, Stauffer Management Company (SMC) presented several by-product recovery processes as alternatives to the high density sludge process for treating acid mine drainage (AMD) from Iron Mountain Mine. SMC's by-product recovery proposal is one of about a dozen that have been evaluated by the PRPs, by EPA, or by others since the early 1980s. None of these proposals has proven feasible because of technical problems, unmarketable by-products, economic infeasibility, lack of commercial precedent, a combination of these factors or other problems. Previous evaluations of by-product recovery alternatives have been reported in feasibility studies, technical memorandums, briefings, and special reports.

The SMC presentation of December 13, 1993, suggested that breakthroughs in SMC's research laboratories have led to new technology that would be applicable to by-product recovery from Iron Mountain AMD. Information presented at the December meeting indicated that one or more by-product recovery options provided more favorable economics than the high density sludge process called for in the second Record of Decision (ROD2). This information has been analyzed and the results have shown that after several types of errors in SMC's evaluation are corrected, by-product recovery is economically unfavorable, and the lowest cost alternative is the high density sludge process prescribed in ROD2.

Corrected SMC Cost Comparison

SMC approached the economic comparison among AMD treatment-only alternatives, and between treatment only and by-product recovery alternatives by presenting abbreviated operation and maintenance (O&M) costs for each alternative. They judged the suitability of each alternative based on these abbreviated estimates.

This approach has several fundamental shortcomings that may not be apparent from casual review. Some of the fundamental problems with SMC's methods are highlighted immediately below, and other problems are identified elsewhere in the text of this memorandum. The most obvious problems are:

- Capital costs were not estimated. This omission invalidates a true comparison of the alternatives.
- Capital equipment for the alternatives was not identified, so overall maintenance requirements and costs were not included in SMC's comparisons.
- The basis for SMC's chemical costs was not always supportable. (In cases of doubt, published cost information was relied upon.)
- Systems designed for long-term use in site remediation are commonly assumed to have a 30-year life.

It is not known if capital equipment SMC would consider installing for recovering by-products would have a 30-year life, or if periodic replacement of the system would occur one or more times during the 30-year period. Annual costs could be much higher than claimed if periodic replacement was required.

In addition to these fundamental difficulties, a number of other errors could be grouped into various categories. The shortcomings in SMC's evaluation of treatment alternatives and of by-product recovery alternatives are not comprehensively covered in this memorandum, but these examples are sufficient to illustrate the lack of substantiation for the comparisons that were presented.

Our use of a method for estimating and comparing costs that is similar to SMC's method is not an endorsement of SMC's approach. It is only an expedient to show how such a comparison would turn out if some corrections are made in some of the material, energy, and labor costs, and in the valuation of recovered by-product.

Examination of the SMC by-product recovery comparisons with the high density sludge process showed that errors falling into at least five categories had been made in performing the comparisons. The errors committed within these five categories are presented in Table 1, and are summarized below.

Material Values and Costs. Although several errors were committed that had only minor impact on the cost comparison (Table 1), one which appears extreme (cadmium value $25,000 to 50,000 per ton) had little impact, while another that seemed comparatively small (caustic soda cost $100 per ton) severely biased the outcome of the comparison. SMC claimed that its cost for caustic soda from internal sources is only $100 per ton compared to an open market price of $300 to 600 per ton. The use of a $100-per-ton cost for this material was revised upward, because if SMC only charged the Iron Mountain Mine treatment plant that amount, the company would suffer a "lost opportunity" to sell caustic soda at the fair market price of at least $300 per ton. Moreover, it is highly unlikely that any other institution that might operate the treatment plant could purchase caustic soda for so low a price, so the lowest market price that could be independently substantiated, $300 per ton, was used in revising the cost comparison.

Derived Values and Costs. SMC valued recovered zinc at $900 per ton, which is the value of high-quality refined zinc slabs, not the value of a 50 percent aqueous sludge containing zinc sulfide and several impurities. A zinc smelter was contacted to ascertain a more realistic value for the zinc sulfide sludge, and, based on the formula they use, the value for zinc sulfide sludge from SMC's recovery process was only $41 per ton.

Another significant error committed by SMC was their assumption that process sludge derived from caustic soda neutralization of the AMD would have dewatering characteristics similar to those for sludges produced with lime. SMC's disposal cost of $15.20 per ton for caustic soda-derived sludge was revised to $89.18 per ton to reflect its poor dewatering properties and the greater difficulty handling it.

Inconsistencies. SMC reported a $1,165-per-ton value for by-product copper in a tabulation of mineral values in AMD sludge, but used a value of $2,000 per ton in their cost comparisons. The $2,000 per ton value is unsubstantiable based on independent cost sources. A compromise value of $1,300 per ton was used (although this is probably too high for cementation copper) in revising the cost comparison.

Several other inconsistencies were noted, and these are also reported in Table 1.

Questionable Basis. The same labor costs were used for all options, irrespective of the complexity of the AMD treatment or by-product recovery system being evaluated. In the revised cost comparisons, labor costs were adjusted to reflect the complexity of the overall system.

Losses of solvent and amine from solvent extraction recovery of sulfuric acid were reported to be "small," amounting to only $20 per day each. No basis was given for these claims, but any losses (which are to be expected) need to be critically examined because they appear to introduce new types of contaminants (organics) into the surface water system.

Sludge Disposal Cost. The costs that were used for sludge disposal for all options were the same, $12.50 per ton. The costs to dispose of process sludges from various processes will actually vary with sludge consistency and drying characteristics, and these cost differences have been estimated in CH2M HILL's Sludge Management Plan of 1993. The costs in this management plan were used to revise SMC's cost comparison.

Corrected Cost Comparisons

The SMC cost comparisons were revised to reflect the corrected costs and recovered by-product values. These comparisons were grouped into the following categories and compiled in corresponding tables:

- Simple Mix Process (Table 2)
- High Density Sludge Process (Table 3)
- Acid Recovery/Copper Cementation/High Density Sludge (Tables 4 and 5)
- Acid Recovery/Copper Cementation//Zinc Sulfide Recovery/High Density Sludge (Tables 4 and 6)
- Ammonium Sulfate Production/Copper Cementation/Zinc Sulfide Recovery/High Density Sludge (Tables 4 and 7)

Simple Mix Versus High Density Sludge

The cost comparison presented by SMC and presented below with original and revised costs was carried out as though all the AMD from Iron Mountain (not just portal flows) would be neutralized in either the simple mix process or the high density sludge process. Treatment of all the runoff from Iron Mountain has not been under active consideration by EPA or the principle responsible parties (PRPs) in any previous communications, and we neither endorse nor propose collection and treatment of site-wide runoff at this time. Nevertheless, SMC's original and our revised cost estimates are compared as though site-wide runoff were to be treated, in order to provide a basis for comparing original and revised costs.

An additional implication of SMC's presentation is that the simple mix process is under serious consideration as an alternative to the high density sludge process. It is not: simple mix was authorized as an interim treatment to compensate for schedule delays by SMC's predecessors in installing a high density sludge plant. The high density sludge process was already known to have practical and economic advantages over simple mix-type processes, as is reaffirmed in the analysis below. Nevertheless, the original and revised costs were compared in the following discussion as though the choice between simple mix and high density sludge was still under consideration, in order to provide a common basis for the evaluation.

Simple Mix. The original and revised costs for the simple mix process, summarized in Table 2, show that SMC's original estimates were too low. SMC's simple mix plant annual operation and maintenance cost estimates were \$2.5 million per year for lime treatment, and \$2.48 million per year for caustic soda treatment. When the true commercial cost for caustic soda and more realistic costs and physical characteristics of simple mix sludge are used for the caustic soda case, the annual costs are more than double the original estimate, to $5.16 million per year.

A much smaller cost increase was found for the simple mix case using lime. The annual operation and maintenance cost increased less than 10 percent to $2.7 million per year from SMC's previously-mentioned estimate of $2.5 million per year, even though the estimated sludge volume more than doubled. The cost increase, stemming from a doubling of the sludge volume, was nearly offset by the lower cost for lime that was reported in published sources.

The revised cost estimates showed that the simple mix process would be nearly twice as expensive using caustic soda than if lime were used as the neutralizing agent.

Conclusions. The bases for many of SMC's cost estimates could not be independently verified, so it is more valid to use the "Revised" estimates provided in this memorandum. The cost to use caustic soda in the simple mix process is significantly higher than the cost to use lime, so lime is the preferred choice for this process.

High Density Sludge. The cost to operate the high density sludge process with caustic soda was compared to the cost with lime in SMC's presentation. Both in SMC's analysis and in the revised estimates, shown in Table 3, the annual operation and maintenance cost to use caustic soda ($4.88 million per year revised versus SMC's original estimate of $2.69 million per year) was greater than the cost for lime ($2.19 million per year revised versus SMC's estimate of $2.59 million per year.)

The original cost comparison by SMC indicated that the cost of using lime provided only a slight advantage over the cost to run the process with caustic soda. Upon revising the estimates using corrected costs, the cost for the caustic soda option rose to more than twice the cost with lime.

Conclusions. The cost to operate the high density process with lime is less than half the cost for the caustic soda case, so lime is the preferred neutralizing agent for Iron Mountain AMD. Moreover, the cost to operate the high density sludge process is lower than the cost for the simple mix process. Therefore the lime-based high density sludge process is preferred over caustic-based high density sludge, and over either simple mix alternative.

By-Product Recovery

SMC proposed recovering several by-products (Table 4) from Iron Mountain AMD, citing recent developments in their laboratories as the basis for reconsidering by-product recovery after it has been rejected so many times in the past. Although laboratory developments are often encouraging when first reported, there is only a small percentage that remain technically feasible through bench- and pilot-scale testing, and only a relatively small percentage of these achieve commercial status. Consequently, SMC's by-product recovery proposals should be regarded as exploratory investigations, and not substantial enough to alter EPA's current plans to install a high density sludge treatment plant.

One of the fundamental shortcomings of SMC's cost analysis, including the revised costs presented in this memorandum, is that capital costs for the proposed by-product recovery processes were not presented. In engineering practice, it is common practice to prepare a preliminary design with material balances, a list of major equipment, a preliminary general arrangement, and an initial capital cost estimate before operation and maintenance (O&M) costs are estimated. SMC indicated that specific process design information was still unavailable, but would be developed in the future. The absence of preliminary process engineering design from which capital and O&M costs are derived makes SMC's proposed by-product recovery proposals and the likelihood of commercial implementation speculative.

Acid Extraction/Copper Cementation/High Density Sludge. In the first by-product recovery proposal, copper is recovered by the cementation process, as currently practiced, sulfuric is recovered by solvent extraction using an unidentified amine, and the remainder of the stream is treated in a high density sludge plant (Table 5). (SMC appears to intend discharging ferrous iron-sulfate and aluminum-containing wastewater from the by-product recovery process. Because dissolved ferrous iron will oxidize to produce more acidity, and because sulfate discharge may be inconsistent with the Basin Plan, we have assumed that AMD from which by-products had been extracted will need to be treated in an alkaline precipitation process before it is discharged. The cost to operate a lime-based high density sludge plant was shown to be lower than simple mix in the preceding portion of this memorandum, so precipitation has been assumed to be carried out in a lime-based high density sludge plant.)

The original cost estimated by SMC ($2.33 million per year) was revised to $2.53 million per year to include added labor to operate the sulfuric acid system, to reflect lower costs for lime and for sludge disposal, and to reflect increased power and maintenance costs for the additional process equipment used to recover the sulfuric acid. The cost to recover copper and sulfuric acid including taking revenues from the sale of by-products into account, is greater than the cost to treat the AMD in a high density sludge plant (although copper recovery as a pretreatment process ahead of high density sludge may be attractive).

Conclusions. It is more expensive to recover copper and sulfuric acid with the proposed by-product recovery scheme than simply to treat AMD in a high density sludge plant. Consequently, high density sludge treatment is the preferred process, based on cost.

Acid Extraction/Copper Cementation/Zinc Sulfide Recovery/High Density Sludge. SMC's estimated cost of $2.11 million per year for this option was revised to correct several errors. In addition to cost revisions for sulfuric acid recovery, there were significant discrepancies between SMC's declared value for zinc sulfide sludge and the value we determined that would be assigned by a commercial zinc smelter. Instead of yielding a profit, it was estimated that zinc recovery would lose a considerable amount of money if implemented at Iron Mountain (Table 6). The revised cost for this option was estimated to be $2.81 million per year.

The cost to recover sulfuric acid, copper, and zinc sulfide ($2.81 million per year) would exceed the cost to treat Iron Mountain AMD in a high density sludge plant ($2.19 million per year).

Conclusions. High density sludge treatment of AMD without by-product recovery is less expensive than acid extraction, copper cementation, and zinc sulfide recovery with final neutralization in a lime-based high density sludge plant and subsequent discharge.

Ammonium Sulfate Production/Copper Cementation/Zinc Sulfide Recovery/High Density Sludge. Conversion of dilute sulfuric acid from the solvent extraction process into ammonium sulfate avoids the energy and maintenance costs of producing concentrated sulfuric acid. This change makes the current alternative of recovering ammonium sulfate slightly less expensive (SMC estimated the cost to be $1.77 million per year) than the preceding alternative, where sulfuric acid was recovered as is shown in Table 7. Nevertheless, after revising SMC's cost estimates to reflect the market price for zinc sulfide and making other adjustments that had been made in previously discussed options, the cost to recover ammonium sulfate, zinc sulfide, and copper and to treat the residual AMD in a high density sludge plant ($2.47 million per year) exceeds the cost to simply treat all the AMD in a high density sludge plant, without recovering by-products ($2.19 million per year).

Conclusions. It is less expensive to treat AMD from Iron Mountain in a high density sludge plant than to recover by-products, as SMC proposed to do in the December 13, 1993, meeting in San Francisco.

Comparison of Revised Costs. The revised costs for simple mix and high density sludge treatments, and for high density sludge treatment of residual AMD after by-product recovery are presented in Table 8. The comparison clearly shows that in all cases by-product recovery is less attractive from a cost standpoint than simply treating all the AMD in a high density sludge plant.

Conclusions. Treatment of AMD from Iron Mountain in a high density sludge plant is less costly than recovering by-products, as proposed by SMC.

Other Comparison Criteria

A variety of criteria, in addition to cost, may be used in comparing the AMD treatment and by-product recovery options discussed above. Some of these criteria are presented in Table 9.

Several advantages were claimed for by-product recovery options during SMC's presentation. The most important among these advantages were a reduction of the sludge volume (sludge elimination by discharging iron- and aluminum-rich water as

SMC proposed was not seriously evaluated because of environmental concerns and potential conflicts with the Basin Plan), cost reductions, and resource recovery. Aluminum and iron are both toxic at the proposed discharge concentrations and iron would oxidize in the receiving stream, depressing the pH and potentially releasing toxic metals in the sediments and the stream bed. As has been shown, cost reductions for resource recovery will not occur.

A factor that was not addressed in SMC's presentation is the use of several hazardous or potentially hazardous materials that are used to recover by-products. Some objections may be raised by concerned interests about the importing and exporting of ammonia and ammonium sulfate, respectively, and about losses of organo-amines and organic solvents into AMD that is released into the environment. For purposes of the current evolution of alternatives, no judgements were made about any of these criteria except for cost.

Another Review of SMC's Resource Recovery Proposal

EPA's high density sludge expert, Stu Herman, attended SMC's resource recovery presentation in December, and he has prepared his comments independently of this cost review. Mr. Herman's review of SMC's proposals is included as an attachment to this memorandum.

Conclusions. Recovery of by-products from Iron Mountain AMD is not cost effective, and the proposed recovery processes appear speculative. The preferred treatment process for Iron Mountain AMD is the high density sludge process, and this process is also assumed to be an integral part of any of SMC's proposed resource recovery schemes. Consequently, design, construction, and operation of the high density sludge plant should not be postponed until by-product recovery processes are developed.

Table 1
Corrections to SMC Resource Recovery Alternatives

Category	SMC Value	Revised Value	Reference[a]
Material Costs			
• Lime	\$40-\$50/ton as $Ca(OH)_2$	\$40-\$50/ton as CaO	CMR
• Caustic soda	\$100-\$330/ton	\$300-\$600/ton	CMR
• Soda ash	\$150/ton (in comparisons)	\$98/ton	CMR
• Cadmium	~\$25,000-\$50,000/ton	\$700-\$800/ton	AMM
Derived Cost			
• Zinc sulfide	\$900/ton zinc	\$41/ton from ZnS sludge	Cominco
• Sludge disposal	\$15.20/ton from caustic	\$89.18/ton from caustic	
Inconsistencies			
• Lime cost	\$50/ton CaO in table versus \$75/ton in comparisons	Used \$50/ton CaO	CMR
• Magnesium hydroxide	No test data on sludge characteristics	Magnesium hydroxide sludge not evaluated	
• Ammonium sulfate	\$38 and \$105/ton in table versus \$65/ton in comparisons	Used \$65/ton	
• Copper scrap	\$1,165/ton in table versus \$2,000/ton in comparisons	Used \$1,300/ton	WSJ
Questional Basis			
• Labor cost	Same for all plants	Adjusted for complexity	
• Solvent losses	No basis given	Noted—not changed	
• Amine losses	No basis given	Noted—not changed	
• High density sludge: bulk density	Not explicitly stated (159 lb/ft^3 calculated from tables)	Used 103 lb/ft^3 in revised calculations	
Sludge Disposal Cost (Lime, only)	\$12.50/yd^3 for all options	\$8.50/yd^3—dense sludge \$10.00/yd^3—simple mix sludge (aerated) \$11.50/yd^3—simple mix sludge (unaerated)	Sludge Management Plan, CH2M HILL 1993

[a] CMR—*Chemical Marketing Reporter*, Vol. 244, No. 23. December 6, 1993.
WSJ—*The Wall Street Journal*, Vol. CXXX, No. 4. January 6, 1994.
AMM—*American Metal Market*. December 15, 1993.
Cominco—Personal communication with Cominco Smelter at Trail, B.C.

Table 2
Comparison of Simple Mix Process Characteristics and Costs

	Lime		Caustic	
	SMC	**Revised**	**SMC**	**Revised**
Solids Formed (ton/day)	63.3 (dry basis) 110 (drying bed)	63.3 (dry basis 253 (drying bed)	19.3 (dry basis) 33.6 (drying bed)	19.3 (dry basis) 129 (drying bed)
Solids Content in Drying Bed (%)	57.5	25	57.5	15
Cake Density in Drying Bed (lb/ft^3)	106	74.6	106	69.2
Cake Volume (yd^3/day)	77	251	24	138
Disposal Cost ($/day)	<961>	<2,510>	<294>	<1,725>
Raw Materials				
• Lime (ton/day) ($/day)	20.73 (CaO) <2,055>	20.73 (CaO) <1,037>		
• Caustic (ton/day) ($/day)			29.6 <2,961>	29.6 <8,883>
Labor Cost ($/day)	<1,488>	<1,488>	<1,488>	<1,488>
Power Cost ($/day)	<767>	<767>	<633>	<633>
Maintenance Cost ($/day)	<1,035>	<1,035>	<854>	<854>
Drying Bed Maintenance Cost ($/day)	<216>	<216>	<216>	<216>
Road Maintenance Cost ($/day)	<337>	<337>	<337>	<337>
Total Daily Cost ($/day)	<6,859>	<7,390>	<6,783>	<14,136>
Annual Net Cost ($ million/yr)	<2.50>	<2.70>	<2.48>	<5.16>

Table 3
Comparison of High Density Sludge Process Characteristics and Costs

	Lime		Caustic	
	SMC	Revised	SMC	Revised
Solids Formed (ton/day)	63.3 (dry basis) 110 (drying bed)	63.3 (dry basis 105 (drying bed)	19.3 (dry basis) 33.6 (drying bed)	19.3 (dry basis) 32.2 (drying bed)
Solids Content in Drying Bed (%)	57.5	60	57.5	60
Cake Density in Drying Bed (lb/ft^3)	159 (est.)	103	159 (est.)	103
Cake Volume (yd^3/day)	58	76	18	23
Disposal Cost ($/day)	<725>	<645>	<225>	<290>
Raw Materials				
• Lime (ton/day) ($/day)	20.73 (CaO) <2,055>	20.73 (CaO) <1,037>		
• Caustic (ton/day) ($/day)			29.6 <2,961>	29.6 <8,883>
Labor Cost ($/day)	<1,488>	<1,488>	<1,488>	<1,488>
Power Cost ($/day)	<1,151>	<1,151>	<1,093>	<1,093>
Maintenance Cost ($/day)	<1,117>	<1,117>	<1,061>	<1,061>
Drying Bed Maintenance Cost ($/day)	<216>	<216>	<216>	<216>
Road Maintenance Cost ($/day)	<337>	<337>	<337>	<337>
Total Daily Cost ($/day)	<7,089>	<5,994>	<7,381>	<13,368>
Annual Net Cost ($ million/yr)	<2.59>	<2.19>	<2.69>	<4.88>

Table 4
Comparison of Individual Byproduct Values

	SMC	Revised
Copper (cementation)		
• Quantity recovered (lb/day)	620	372
• Value ($/day)	372	242
• Scrap iron cost ($/day)	<46>	<46>
Sulfuric Acid		
• Quantity recovered (lb/day)	32,333	32,333
• Value ($/day)	1,212	1,212
• Amine cost ($/day)	<20>	<20>
• Solvent cost ($/day)	<20>	<20>
• Labor cost ($/day)	0	<744>
Zinc Sulfide Sludge		
• Quantity recovered (lb/day)	4,666	4,666
• Value ($/day)	704	96
• Sodium hydrosulfide cost ($/day)	<183>	<183>
• Labor cost ($/day)	0	<744>
Ammonium Sulfate		
• Quantity recovered (lb/day)	106,612 (as 38% solution)	106,612 (as 38% solution)
• Value (%/day)	1,317	1,317
• Ammonia cost ($/day)	<1,358>	<1,358>
• Labor cost ($/day)	0	<744>

Table 5
Comparison of Acid Extraction and Copper Cementation Costs and Returns (Lime Neutralization with High Density Sludge Process)

	SMC	Revised
Copper (cementation)		
- Quantity recovered (lb/day)	620	372
- Value ($/day)	372	242
- Scrap iron cost ($/day)	<46>	<46>
- Net value ($/day)	326	196
Sulfuric Acid Recovery		
- Quantity recovered (lb/day)	32,333	32,333
- Value ($/day)	1,212	1,212
- Reagent (solvent plus amine) cost ($/day)	<20+20>	<20+20>
- Labor cost ($/day)	0	<744>
- Net value ($/day)	1,172	428
Neutralization Treatment		
- Solids formed (ton/day)	42.3 (dry basis) 73.6 (drying bed)	42.3 (dry basis) 70.4 (drying bed)
- Cake volume (yd^3/day)	51.4	50.6
- Disposal cost ($/day)	<642>	<430>
- Lime (ton/day) ($/day)	12.1 (as CaO) <1,200>	12.1 (as CaO) <605>
- Labor cost ($/day)	<1,488>	<1,488>
- Power cost[a] ($/day)	<2,767>	<3,151>
- Maintenance cost ($/day)	<1,235>	<1,317>
- Drying bed maintenance ($/day)	<216>	<216>
- Road maintenance cost ($/day)	<337>	<337>
- Net value <loss> ($/day)	<7,885>	<7,544>
Overall Value Recovered <lost>		
($/day)	<6,387>	<6,920>
($ million/year)	<2.33>	<2.53>

[a] Includes combined requirements for cementation, acid recovery, and neutralization.

Table 6
Comparison of Acid Extraction, Copper Cementation, and Zinc Sulfide Precipitation Costs and Returns
(Lime Neutralization with High Density Sludge Process)

	SMC	Revised
Copper (cementation)		
• Quantity recovered (lb/day)	620	372
• Value ($/day)	372	242
• Scrap iron cost ($/day)	<46>	<46>
• Net value ($/day)	326	196
Sulfuric Acid Recovery		
• Quantity recovered (lb/day)	32,333	32,333
• Value ($/day)	1,212	1,212
• Reagent (solvent plus amine) cost ($/day)	<20+20>	<20+20>
• Labor cost ($/day)	0	<744>
• Net value ($/day)	1,172	428
Zinc Sulfide Sludge Recovery		
• Quantity recovered (lb/day)	4,666	4,666
• Value ($/day)	704	96
• Sodium hydrosulfide cost ($/day)	<183>	<183>
• Labor cost ($/day)	0	<744>
• Net value ($/day)	521	<831>
Neutralization Treatment		
• Solids formed (ton/day)	40.2 (dry basis) 69.9 (drying bed)	40.2 (dry basis) 67 (drying bed)
• Cake volume (yd^3/day)	49	48.2
• Disposal cost ($/day)	<610>	<410>
• Lime (ton/day) ($/day)	11.7 <1,155>	11.7 <583>
• Labor cost ($/day)	<1,488>	<1,488>
• Power cost[a] ($/day)	<2,767>	<3,151>
• Maintenance cost ($/day)	<1,235>	<1,317>
• Drying bed maintenance ($/day)	<216>	<216>
• Road maintenance cost ($/day)	<337>	<337>
• Net value <loss> ($/day)	<7,808>	<7,502>
Overall Value Recovered <lost>		
($/day)	<5,789>	<7,709>
($ million/year)	<2.11>	<2.81>

[a] Includes combined requirements for cementation, acid recovery, zinc recovery, and neutralization.

Table 7
Comparison of Ammonium Sulfate Production (from Recovered Acid), Copper Cementation, and Zinc Sulfide Precipitation Costs and Returns (Lime Neutralization with High Density Sludge Process)

	SMC	Revised
Copper (cementation)		
• Quantity recovered (lb/day)	620	372
• Value ($/day)	372	242
• Scrap iron cost ($/day)	<46>	<46>
• Net value ($/day)	326	196
Ammonium Sulfate Production		
• Quantity recovered (lb/day 38% solution)	106,612	106,612
• Value ($/day)	1,317	1,317
• Reagent (solvent plus amine plus ammonia) cost ($/day)	<20+20+1,358>	<20+20+1,358>
• Labor cost ($/day)	0	<744>
• Net value ($/day)	<81>	<825>
Zinc Sulfide Sludge Recovery		
• Quantity recovered (lb/day)	4,666	4,666
• Value ($/day)	704	96
• Sodium hydrosulfide cost ($/day)	<183>	<183>
• Labor cost ($/day)	0	<744>
• Net value ($/day)	521	<831>
Neutralization Treatment		
• Solids formed (ton/day)	40.2 69.9 (drying bed)	40.2 67 (drying bed)
• Cake volume (yd^3/day)	49	48.2
• Disposal cost ($/day)	<610>	<410>
• Lime (ton/day) ($/day)	11.7 <1,155>	11.7 <583>
• Labor cost ($/day)	<1,488>	<1,488>
• Power cost[a] ($/day)	<767>	<1,151>
• Maintenance cost ($/day)	<1,035>	<1,117>
• Drying bed maintenance cost ($/day)	<216>	<216>
• Road maintenance cost ($/day)	<337>	<337>
• Net value <loss> ($/day)	<5,605>	<5,302>
Overall Value Recovered <lost>		
($/day)	<4,839>	<6,762>
($ million/year)	<1.77>	<2.47>

[a] Includes combined requirements for cementation, ammonium sulfate recovery, zinc recovery, and neutralization.

Table 8
Comparison of Revised Treatment and Byproduct Recovery Options

	Lime and Simple Mix	Caustic and Simple Mix	Lime and High Density Sludge	Caustic and High Density Sludge	Cementation, Acid Recovery, and High Density Sludge	Cementation, Acid Recovery, Zinc Sulfide Recovery, and High Density Sludge	Cementation, Ammonium Sulfate Recovery, Zinc Sulfide Recovery, and High Density Sludge
Copper (Cementation)							
• Quantity Recovered (lb/day)					372	372	372
• Value ($/day)					242	242	242
• Scrap Iron Cost ($/day)					<46>	<46>	<46>
• Net Value					196	196	196
Sulfuric Acid Recovery							
• Quantity Recovered (lb/day)					32,333	32,333	
• Value ($/day)					1,212	1,212	
• Operating Costs ($/day)					<784>	<784>	
• Net Value ($/day)					428	428	
Zinc Sulfide Sludge Recovery							
• Quantity Recovered (lb/day)						4,666	4,666
• Value ($/day)						96	96
• Operating Costs ($/day)						<927>	<927>
• Net Value ($/day)						<831>	<831>
Ammonium Sulfate Recovery							
• Quantity Recovered (lb/day)							106,612
• Value ($/day)							1,317
• Operating Costs ($/day)							<2,142>
• Net Value ($/day)							<825>
Neutralization Treatment							
• Sludge Quantity (dry tons/day)	63.3	19.3	63.3	19.3	42.3	40.2	40.2
• Disposal Cost ($/day)	<2,510>	<1,725>	<645>	<290>	<430>	<410>	<410>
• Operating Costs ($/day)	<4,880>	<12,411>	<5,346>	<13,078>	<7,114>	<7,092>	<4,892>
• Net Cost ($/day)	<7,390>	<14,136>	<5,994>	<13,368>	<7,544>	<7,502>	<5,302>
Overall Value <cost>							
($/day)	<7,390>	<14,136>	<5,994>	<13,368>	<6,920>	<7,709>	<6,762>
($ million/year)	<2.70>	<5.16>	<2.19>	<4.88>	<2.53>	<2.81>	<2.47>

Table 9
Qualitative Comparison of Treatment and Recovery Alternatives

Comparison Criteria	Lime and High Density Sludge	Cementation, Acid Recovery, and High Density Sludge	Cementation, Acid Recovery, Zinc Sulfide Recovery, and High Density Sludge	Cementation, Ammonium Sulfate Recovery, Zinc Sulfide Recovery, and High Density Sludge
Discharge Water Quality	Removes toxic metals, copper, zinc, and cadmium Removes base metals, iron, and aluminum Eliminates acidity. Reduces dissolved solids 10- to 20-fold.	Removes toxic metals, copper, zinc, and cadmium Removes base metals, iron, and aluminum Eliminates acidity. Reduces dissolved solids 10- to 20-fold. **Introduces organic contaminants from solvent extraction (acid recovery)** **Introduces amine (aquatic toxicity) contamination from solvent extraction (acid recovery)**	Removes toxic metals, copper, zinc, and cadmium Removes base metals, iron, and aluminum Eliminates acidity. Reduces dissolved solids 10- to 20-fold. **Introduces organic contaminants from solvent extraction (acid recovery)** **Introduces amine (aquatic toxicity) contamination from solvent extraction (acid recovery)**	Removes toxic metals, copper, zinc, and cadmium Removes base metals, iron, and aluminum Eliminates acidity. Reduces dissolved solids 10- to 20-fold. **Introduces organic contaminants from solvent extraction (acid recovery)** **Introduces amine (aquatic toxicity) contamination from solvent extraction (acid recovery)**
Recovery of Saleable Byproducts	No saleable byproducts produced	Recovers crude copper in iron/iron oxide matrix with maximum net value of $196/day.	Recovers crude copper in iron/iron oxide matrix with maximum net value of $196/day.	Recovers crude copper in iron/iron oxide matrix with maximum net value of $196/day.
Recovery of Saleable Byproducts (cont.)		Recovers sulfuric acid (unspecified purity or concentration) with estimated net value of $428/day.	Recovers sulfuric acid (unspecified purity or concentration) with estimated net value of $428/day. Recovers crude zinc sulfide sludge with estimated net loss of <$831>/day	Recovers sulfuric acid (unspecified purity or concentration) with estimated net value of $428/day. Recovers crude zinc sulfide sludge with estimated net loss of <$831>/day

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Cost Comparison	Daily net loss of <$6,300> on operation and maintenance. Lowest capital cost alternative Lowest present value	Daily net loss of <$6,900> on operation and maintenance. Second lowest capital cost alternative Second lowest present value	Daily net loss of <$7,700> on operation and maintenance. Probable highest (or second highest) capital cost alternative High present value	Daily net loss of <$6,800> on operation and maintenance. Probable second-highest (or highest) capital cost alternative High present value
Sludge Quantity and Disposal Cost	76 yds^3/day <$645>/day	51 yds^3/day <$430>/day	48.2 yds^3/day <$410>/day	48.2 yds^3/day <$410>/day
Hazardous Materials Shipment and Usage				
Lime	Imported and used	Imported and used	Imported and used	Imported and used
Ammonia				Imported, used, and exported in product
Sodium Hydrosulfide			Imported and used	Imported and used
Amine Lixiviant		Imported to make up losses	Imported to make up losses	Imported to make up losses
Solvent (e.g., kerosene)		Imported to make up losses	Imported to make up losses	Imported to make up losses

Bethlehem Steel Corporation

BETHLEHEM, PA 18016

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To: Jim Mavis/CH2M Hill

From: Stewart Herman

Date: December 20, 1993

Subject: Iron Mountain Mine
Stauffer Proposal for Resource Recovery

Project: EPA Prime Contract No. 68-W9-0031

Introduction

At a meeting at EPA Region IX offices in San Francisco on December 13, representatives of Stauffer Management Company (SMC), the principally responsible party at Iron Mountain Mines (IMM), presented a preliminary study of resource recovery at IMM. SMC presented a rough timetable for the research, engineering, and construction required to have a resource recovery system up and running. That schedule showed a start-up date of mid-1997. As a result of their work on resource recovery, SMC would like to have the EPA rescind their requirements for both: 1.) high density sludge treatment of the acid mine drainage (AMD) and 2.) the construction of an expansion of the Spring Creek Debris Dam.

Presentations were also made on the characterization of the metals loadings in Slick Rock Creek basin and the construction of the aerated simple mix plant at Minnesota Flats.

Resource Recovery

Introduction

The presentation began with an overhead showing the overall philosophy of the resource recovery proposal. According to SMC, the sources of contaminants would be minimized, the products recovered for sale would be maximized, and the sludge produced for landfill disposal would be minimized.

Block diagrams were presented of aerated simple mix and the high density sludge process as starting points for the discussion. Several proposals for resource recovery were then presented. These presentations also consisted of block diagrams with no estimates of the equipment necessary to perform the various unit operations that were represented in each block.

Acid Mine Drainage Composition

The resource recovery plans that were presented assumed that the flows from the Richmond Portal, Lawson Portal, Old Mine/No.8, Big Seep, and the Brick Flat Bypass would be combined to form the AMD flow to be treated. The following table lists the average flow and concentrations of the major contaminants in the combined stream.

Flow gpm	Contaminant, ppm									
	Al	As	Cd	Cu	Fe	Pb	Mn	Zn	SO_4	TDS
524	327	5.3	1.8	59	2,466	0.5	5.1	249	11,273	48,912

The inclusion of two relatively dilute streams, the Big Seep and the Brick Flat Bypass, reduce the contaminant concentrations well below that used in the Treatability Studies conducted by Weston for SMC. The much lower concentration of sulfate in particular will cause the aerated simple mix system to produce a sludge with a lower solids concentration than that seen in the Weston studies. This becomes important in the resource recovery presentations where sludge volumes are compared between simple mix and the high density sludge process. The maximum flow rates for the various streams are shown in the presentation, but no mention is made of how those maximums are to be handled. All designs are for the average flow only.

Option 1. Substitute NaOH for Lime in Simple Mix

The first proposal is a simple substitution of sodium hydroxide for lime in the aerated simple mix process. This proposal recovers no products for sale, but reduces the pounds of solids precipitated. The sulfate ions which would have been precipitated as gypsum, $CaSO_4$-$2H_2O$, would be passed to the receiving waters as sodium sulfate, Na_2SO_4. According to the presentation, the **weight** of solids precipitated would be reduced by almost 70 percent. However, this option **does not reduce** the **volume** of solids to be handled, and, as discussed below, can **increase** that volume significantly. Also, the effects of discharging approximately 105,000 pounds per day of soluble sodium sulfate to the receiving waters must be evaluated before this proposal can be considered.

A summary table that presents the sludge generation rates for lime, caustic, and magnesium hydroxide also estimates the volume of "dry" sludge to be hauled to Brick Flat Pit for ultimate disposal. The volumes of material removed are all assumed to contain 57.5 percent solids. That is in error. With the lower concentration of gypsum, the aerated simple mix will produce a sludge that settles to no more than 25 percent solids in the filter ponds. Also, the use of sodium hydroxide in the aerated simple mix system will produce a sludge containing about five percent solids at final dilution in the filter ponds. Although the top layer of sludge in a drying bed might lose some water by evaporation during the dry California summer, the vast majority of the sludge will remain very wet. Also, without the gypsum to provide drainage, the gelatinous metal hydroxide sludges will quickly plug the sand filter layer, preventing the drainage of water. Removal of the wet sludge from the drying basins would be difficult and material with a very high water content would be placed in Brick Flat Pit. If the aerated, simple mix, caustic-neutralized slurry is filtered on a belt press prior to disposal, a cake containing about 25 percent solids will be produced. The following table lists the projected cake percent solids, cake density, and cake volume based on the total weight of solids shown in the SMC's summary table. All calculations assume the specific gravity of the solids to be 2.9.

Parameter	**Aerated Simple Mix**			**High Density Sludge**	
	Caustic		**Lime**	**Caustic**	**Lime**
	Filter Pond	**Belt Press**	**Filter Pond**		
Dry Solids, lbs/day	38,687	38,687	126,508	38,687	126,508
Cake Solids, percent	5	25	25	60	60
Cake Density, lbs/ft^3	64.5	74.6	74.6	103	103
Cake Volume, ft^3/day	12,000	2,074	6,790	626	2,047

The only way that this proposal is feasible is to utilize the high density sludge process, which will produce a dense sludge from caustic neutralization of the metal hydroxides. However, the high density sludge process will still discharge a high concentration of sodium sulfate to the receiving waters if caustic is used as the neutralizing agent. It should be noted that the high density sludge process using lime generates about the same volume of solids per day as aerated simple mix with caustic and a filter press. However, the high density sludge process with lime reduces the total dissolved solids discharged to surface waters by about 75,000 lbs/day.

SMC used a cost for sodium hydroxide of $100/ton. The price of sodium hydroxide is currently low due to the very high demand for chlorine, which produces caustic as a by-product. Average sodium hydroxide costs range closer to $300/ton over the long term. SMC stated that they could maintain the low cost due to their purchasing power in the chemical marketplace. However, that assumes that SMC will be the continuing operator of the treatment facility. They have not yet agreed to operate the facility at all. If the operation of the facility falls to the state or federal government, the cost of sodium hydroxide will be much higher than that shown by SMC.

SMC stated that this proposal was shown as an example of what could be done. They did mention several times that they were not likely to seriously consider implementation of this option because other processes showed more promise. Unfortunately, many of the other processes discussed involve caustic precipitation of metal hydroxides. Therefore, those options are also subject to the same problems just discussed.

Option 2. Recovery of Acid and Copper Followed by Caustic Neutralization

This option proposes to remove the acid from solution by mixing an amine in an organic solvent, e.g. kerosene, and then mixing the amine/solvent mixture with the AMD. The amine would adsorb the acid and then the amine/solvent mixture would be separated from the AMD. The amine/solvent mixture would be heated and mixed with water to release the acid. The acid would be concentrated for sale as a by product and the amine/solvent mixture would be recycled. The copper would then be removed from the acid free AMD by cementation with iron. The acid and copper free AMD would be treated by aerated simple mix with caustic.

The costs associated with acid recovery in this fashion are unknown, even though a cost is shown in a later spreadsheet. There are at least four major problems with this proposed acid recovery step. First, the kinetics of the various reactions must be studied to determine if the amine will indeed remove a large portion of the acid from the AMD in question. Competition for adsorption sites with sodium, potassium, and other cations must be considered. Second, there must be some evaluation of the capital equipment necessary to effect the acid removal. At the very least, there will be two continuously stirred reactors, two decanters, and a still to concentrate the acid. The amortization of the capital cost of all of that equipment must be considered in the long term operating costs. Third, the amount of resin and organic lost to the AMD must be known, both to allow for calculation of operating costs and to determine the effects of those materials on the receiving waters. Finally, there must be a market for the acid produced. The price obtained for the acid will depend upon the concentration and purity of the product. Neither of those factors are known at this time.

Cementation of copper by iron is being practiced now and should be a continuing part of the final treatment scenario. SMC credits one dollar for every pound of copper recovered by cementation. That seems high, since electrolytic grade copper does not sell for that much.

Caustic neutralization of the acid and copper free AMD by aerated simple mix will be subject to the same problems as discussed in option 1. The only "cost reduction" that occurs in the neutralization step is a lower use of caustic due to the removal of the acid and copper.

Option 3. Recovery of Ammonium Sulfate and Copper Followed by Caustic Neutralization

This option is identical to option 2, except that the sulfuric acid is converted to an ammonium sulfate solution for sale. The distillation step for sulfuric acid is thus replaced by a continuously stirred reactor and a distillation column to increase the concentration of the ammonium sulfate. The same cost uncertainties exist in this option as well as in option 2. The purity of the ammonium sulfate must be determined and a market for the solution must also be located. The caustic neutralization step is identical to option 2, and therefore, subject to the same problems.

Option 4. Recovery of Ammonium Sulfate and Copper Followed by Sulfide Precipitation of Zinc and Caustic Neutralization

This option takes the acid and copper free AMD from option 3 and precipitates the zinc as zinc sulfide by the addition of sodium hydrosulfide and caustic. The remaining solution is then either discharged directly or neutralized with aerated simple mix utilizing caustic.

The zinc precipitation step shown in this option will also precipitate the ferrous iron, thus producing a very heavily contaminated zinc sulfide product. The cost credited for the recovered zinc is shown as $0.50/pound. Pure zinc metal may be worth that price, but zinc sulfide, let alone highly contaminated zinc sulfide, will not command that price. In fact, this product will be so highly contaminated that it will be essentially worthless. Sulfide sludges can be extremely difficult to filter and dry. No mention is made of how this material will be dried for shipment.

Direct discharge of the remaining AMD solution will be undesirable as it will still cause aluminum to precipitate in the receiving waters. Aluminum precipitates have been shown to be toxic to fish life because they clog gill surfaces and suffocate the fish. SMC is in error in assuming that the majority of the iron will pass through the sulfide precipitation process. However, if it did, it would cause further damage to the receiving waters since it would remove dissolved oxygen and coat the stream bottoms with precipitate.

The caustic neutralization step will still produce a very dilute, gelatinous sludge, as it would in all the other options.

Cost Spreadsheets for All Options

It is my opinion that not enough information is available to make a reasonable calculation of the operating costs for any of the options except option 1, caustic neutralization. As noted earlier, the capital costs will be substantial for some of the equipment involved in options 2 through 4, and those costs must be amortized over the life of the facility.

The purity of the recovered products will have a great deal to do with the price obtained for them. Prices for the materials to be recovered cannot be assumed to be at or above the market value of absolutely pure products.

Characterization of Metals Loading in Slick Rock Basin

SMC is conducting pumping tests on the flooded section of Old Mine/No.8. They have succeeded in lowering the water level in the mine and have dried up a major seep from that mine complex. However, the water level in the mine is still above the level of Slick Rock Creek. Thus, the mine could be contributing contaminated water to the creek bottom. It seems logical that the mine water level will have to be lowered to less than the elevation of Slick Rock Creek before the true contribution of contaminants from Old Mine/No.8 to the creek is known. It is also possible that in pumping the mine water elevation down, Slick Rock Creek could go from an influent to an effluent stream and contribute a considerable volume of water to the Old Mine/No.8 complex. In that case, the pumping rate would have to be raised substantially to keep the mine water elevation below the elevation of Slick Rock Creek. As the mine water elevation is lowered, it is also possible that the contaminant levels in the water could increase. Under totally flooded conditions, the oxygen concentration in the mine is limited to that in the incoming groundwater. When the sulfide deposits are exposed to air and water as the mine is pumped down, the oxidation rate of the sulfide could increase dramatically.

The results of these tests should be monitored closely. The volume and contaminant concentrations from the pump discharge will directly affect the operation of both the simple mix and high density sludge plants at Minnesota Flats. As the amount of dilute AMD entering the plant increases, the solids concentration in the sludge produced by aerated simple mix will decrease and the current annual sludge storage volume may be inadequate.

If you have any questions about these comments, please call me at (215)-694-6476.

S. T. Herman

S. T. Herman

cc: John Spitzley/Redding
Jim Stefanoff/Seattle