EPA-600/2-77-215
November 1977

Environmental Protection Technology Series

COST ASSESSMENT FOR THE EMPLACEMENT OF HAZARDOUS MATERIALS IN A SALT MINE

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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DISCLAIMER

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The Solid and Hazardous Waste Research Division contributes to these program objectives by conducting research to promote improved solid waste management and the environmentally safe management and disposal of hazardous wastes. This report presents results of an economic evaluation of the non-radioactive hazardous wastes storage in underground mine openings.

Francis T. Mayo
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ABSTRACT

This report presents the results of an economic evaluation of the storage of nonradioactive hazardous wastes in underground mine openings. This study is a part of a continuous effort to find a new and better method of disposing or storing hazardous wastes in an environmentally acceptable manner. The technical assessment of the hazardous waste storage in underground mine openings performed in an earlier study (EPA-600/2-75-040) indicated that long-term storage of hazardous wastes in a room and pillar type salt mine was an environmentally acceptable method provided that certain precautions are taken. This study is performed to develop the cost data associated with the storage of hazardous wastes in a typical room and pillar type salt mine, including the capital and operating costs. The intent of the study is to reveal economic sensitivity of various parameters involved in the underground storage of hazardous wastes. In order to develop the cost data, this study also involved characterization of the wastes and conceptual design of the waste receiving, treatment, containerization, and storage facilities.

The major work tasks are (1) development of the design criteria including waste characteristics, storage concept, treatment requirements, and selection of the study mine; (2) conceptual design of the surface and subsurface facilities; and (3) estimation of the capital and operating costs. Design information based on actual experience was not available for the storage of hazardous wastes in a salt mine at this time. This study considered five possible alternative concepts of storing hazardous wastes in a salt mine that involved variations in the plant size, the waste composition, and the storage method.

It was concluded that the underground storage of hazardous wastes should be in a systematic manner to allow controlled handling, segregated storage of different wastes, maintenance of stored waste, inventorying of the stored waste, and long-term protection of the environment. To meet these criteria, it was decided to convert all hazardous wastes to solid form, remove free water and oil, and containerize the waste before placing it in the mine. Cementizing the waste instead of the containerization was considered as an alternative storage method.

The cost of storing hazardous wastes in a salt mine depended considerably on the plant capacity,the waste characterization, and the storage method. In the case of different plant capacities, the unit cost per ton (waste management fee) increased from $173 to $424 (per ton stored) as the storage loading reduced from 1,030 tons per day to 103 tons per day.

The unit cost of storing the waste containerized in steel drums (420 TPD stored waste) was $187 (per ton stored); whereas the cost of storing cementized waste was $102. The waste characteristics also had significant

effects on the storage cost. The unit cost for storing all residue type hazardous waste (420 TPD stored waste) was $187. The cost increased to $298 when approximately 30 percent of the waste is in liquid form requiring chemical treatment.

This report is submitted in fulfillment of Contract No. 68-03-2430 by Bechtel Corporation under the sponsorship of the U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Solid and Hazardous Waste Research Division (EPA, MERL, SHWRD). Work for this report was conducted during the period of July 1976 to May 1977.

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ABBREVIATIONS AND UNIT CONVERSION

Abbreviations

EPA	--	Environmental Protection Agency
SHWRD	--	Solid and Hazardous Waste Research Division
MERL	--	Municipal Environmental Research Laboratory
ISCO	--	International Salt Company
BPT	--	Best Practical Technology
TPD	--	Ton Per Day
W, H, L	--	Width, Height, Length
cfm	--	cubic foot per minute
lb/hr	--	pounds per hour
sq ft	--	square foot
ft	--	foot
hp	--	horsepower
gpm	--	gallon per minute

Unit Conversion

British

1 acre	=	0.405 hectare
1 foot	=	0.3048 m
1 inch	=	2.54 cm
1 square foot	=	0.0929 m^2
1 cubic foot	=	0.02832 m^3
1 gallon	=	3.785 liters
1 ton (short)	=	0.9072 metric ton
$1.0/ton	=	$1.1023/metric ton

ACKNOWLEDGMENTS

The project team wishes to acknowledge the Project Officer, Mr. Robert E. Landreth of the Solid and Hazardous Waste Research Division, Municipal Environmental Research Laboratory (SHWRD, MERL), Cincinnati, for his continued support and guidance throughout the study. We wish also to acknowledge Kali und Salz AG, Herfa-Neurode, West Germany, for allowing C. H. Jacoby of ISCO to visit their hazardous waste storage plant and providing mine and plant operational information.

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Section 1

INTRODUCTION

This is the final report on the study "Cost Assessment for the Emplacement of Hazardous Materials in A Salt Mine," conducted for the U.S. Environmental Protection Agency (EPA) under Contract No. 68-03-2430.

The promulgation of air and water pollution control regulations has resulted in more effective removal of contaminants from waste streams, especially the hazardous constituents in many industrial effluent streams. These cleanup activities have resulted in an increased quantity of concentrated hazardous wastes that must be disposed of. Disposal of hazardous wastes in a manner that isolates them from the environment is becoming a difficult problem throughout the country.

In a continuing effort to find a new and improved method of disposing of or storing hazardous wastes in a manner both economically reasonable and environmentally acceptable, EPA has been supporting a number of studies on the subject of nonradioactive hazardous waste disposal, including offshore incineration, secured landfill, chemical stabilization, encapsulation, and isolation.

One of these studies was "Evaluation of Hazardous Wastes Emplacement in Mined Openings" (EPA-600/2-75-040), supported by the Solid and Hazardous Waste Research Division (SHWRD) of the Municipal Environmental Research Laboratory, EPA (Ref. 1). The study, conducted by Fenix and Scisson, Inc., provided an assessment of the technical feasibility and environmental acceptability of emplacing hazardous industrial wastes in underground mines. The study concluded that storing hazardous industrial wastes in a room and pillar type salt mine would be an environmentally acceptable method of managing hazardous waste, provided that the recommended procedures of site selection, treatment, containerization, and waste handling are followed. In view of this assessment EPA decided that an economic evaluation of the concept should be conducted. This economic evaluation is the subject of this report.

OBJECTIVES OF THE STUDY

This study is to provide EPA with necessary cost information to enable the Agency to make sound decisions on future commitments of resources regarding the emplacement of hazardous wastes in underground storage facilities. Such commitments should include studies on geological assessment of available mines, characterization of hazardous waste suited for the underground storage, and various research and development efforts leading to a demonstration project.

This study provides EPA with the economic data for a review of the costs that are associated with emplacement of hazardous wastes in a room and pillar type salt mine. The study also discusses the economic sensitivity of various parameters involved in the underground emplacement of hazardous wastes. In order to develop the cost data, this study involved characterization of the hazardous waste and conceptual design of the waste receiving, treatment, containerization, and storage facilities.

In this study, a "typical" salt mine located in a bedded salt deposit suitable for storage of hazardous wastes has been used as a basis for design of the required facilities and for cost estimation. The cost estimate includes:

- The probable cost of acquiring land and the construction of surface facilities necessary for waste receiving, unloading, treatment, containerization, and staging.
- The probable cost of acquiring the mine and the construction of underground facilities necessary for waste hoisting, transportation, and storage.
- The direct operating costs, including chemicals, containers, utility, and labor.
- The indirect operating costs, including taxes and insurance and administration and general overhead. This includes costs for public relations and education and long-term liability insurance.

These costs were estimated from conceptual designs of the system. Cost data were obtained from both published literature and Bechtel historical cost data.

PROJECT METHODOLOGY

To fulfill the objectives of the economic evaluation, four major tasks were performed for this study:

(1) Development of Design and Operating Criteria
- -- Characteristics of received waste
- -- Characteristics of stored material
- -- Required treatment
- -- Typical salt mine

(2) Conceptual Design
- -- Surface facility
- -- Subsurface facility

(3) Cost Estimates
-- Capital costs
-- Operating costs

(4) Economic Analyses of Overall Operation

Characteristics of Received Wastes

The available literature was reviewed pertaining to the characteristics of hazardous wastes. A visit was made to the hazardous waste storage plant of Kali und Salz A.G. at Herfa-Neurode in West Germany, the only known underground hazardous waste storage facility. The trip report to the Kali und Salz plant is included in Appendix F.

It was apparent from the literature that at the present time the characterization and inventory of hazardous wastes are incomplete. Although many investigations for characterization and inventory have recently started, they are as yet incomplete, and their results are not available for this study. It is also expected that the characteristics of hazardous wastes (i.e., both quantity and composition) will be changed rapidly as new laws and new management programs are implemented.

From these findings, it was concluded that the hazardous waste characteristics to be used for the study would be of a general nature, reflecting a wide range of waste types, but specific enough to reveal the requirements of different treatment and handling methods. The waste characteristics used for this study are presented in Section 3.

Characteristics of Stored Materials and Required Treatment

The waste can be stored to be easily retrievable as in a warehouse operation or emplaced for long-term storage as in a secured landfill operation with retrievability only in an emergency. Some of the design criteria for easily retrievable storage are, however, not compatible with those for long-term secured storage. For example, easily retrievable storage requires an access to each and every container and open space for retrieval operation, whereas long-term secured storage requires isolation of the stored waste by construction of a barrier or backfilling of the void space with impermeable material. Long-term secured storage of the waste may involve conversion of the waste to more stable form before the storage, while retrievable storage for future resource recovery may prefer storage of the waste as it is received. It is apparent that waste storage with easy retrieval involves use of more space and probably costs more for a unit weight of the stored waste than long-term storage.

Early in the study, it was decided that for this study, the underground waste emplacement should be based on long-term secured storage. Retrieving the long-term stored waste would be considered only in an emergency and when no other alternative is available. Such an emergency retrieval could be required if the long-term storage is later found to be unacceptable because of a public safety reason and the stored waste had to be removed from the underground storage. However, in order to develop cost data associated with short-term storage of the waste and its retrieval, the cases in which a portion of the waste is stored temporarily and later retrieved were also considered.

Hazardous wastes for long-term storage are treated and containerized before storage so that perpetual maintenance of the long-term stored material will not be required. For the purpose of this study, treatment of hazardous waste was assumed to be based on the best practical technology (BPT); that is, waste handling and treatment is based on proven technology at reasonable cost, using readily available equipment. The handling of plant effluents was designed to have a minimum impact on the local community waste treatment facility. Details of the storage concept, treatment requirements, and design criteria are included in Sections 3 and 4.

Typical Salt Mine

The technical assessment report (EPA-600/2-75-040) indicated that a room and pillar type salt mine is the most suitable mine for the long-term storage of hazardous wastes. An actual mine representing a typical room and pillar type salt mine in a bedded salt deposit was selected for this study to form a base from which design, cost estimating, and operating information could be obtained. The mine selection criteria identified in the EPA technical assessment report were used for selecting the case mine. The selection process also considered the availability of design information. The mine selection procedure and a description of the selected mine are included in Section 3.

Conceptual Design

Conceptual design of the surface and subsurface facilities and a description of their operating plans were necessary for the cost estimation. The surface facilities include buildings, civil structures, and equipment necessary for receiving and unloading the waste, for temporary storage and treatment, and for containerization, staging, and service activities. The subsurface facilities include buildings, civil structures, and equipment necessary for hoisting, transportation, and storage of the waste. The subsurface facilities also include underground service buildings.

Design of the base case which represents the selected plant capacity and operating mode was based on the best practical technology, namely the demonstrated technology of a reasonable cost. This study also evaluated three capacities of the same plant concept, an alternative waste type, and an alternative storage concept. Criteria for these alternatives (Cases 1 through 5) are further discussed in Sections 3 and 4. The design of the surface and subsurface facilities is described in Section 4.

Cost Estimates and Economic Analysis of Overall Operation

The cost estimation, based on the conceptual design, includes capital and operating costs for all activities from receiving the waste at the plant gate to its emplacement in the mine. The costs associated with decommissioning the facility and long-term liability insurance were also considered. An estimating method consistent with the conceptual nature of the design and operating information was employed for this study. This included informal vendor contacts and extrapolation from published data and Bechtel historical cost data. All cost data assume first quarter 1977 price and wage levels for the selected location.

The capital investment was obtained from the cost summaries of the buildings, civil structures, equipment, piping, electrical and control facilities, and mine rehabilitation. The operating cost was obtained from the costs of labor and material, and the fixed cost. The unit cost per ton (waste management fee) was estimated using discounted cash flow methodology. Details of the cost estimates -- methodology, criteria, and results -- are included in Section 5. Details of the economic analysis are included in Section 6.

Section 2

SUMMARY AND RECOMMENDATIONS

The primary objectives of this study are to provide a conceptual design of the facilities necessary for long-term storage of hazardous wastes in a salt mine and to estimate the capital and operating costs of such a storage plant. The major work tasks to accomplish these objectives are:

- The development of design and operating criteria including waste character, storage concept, treatment requirements, and selection of the study mine.
- A conceptual design of the surface and subsurface facilities, preliminary specification of equipment, building, and mine rehabilitations, and development of a facility operating plan, including an estimation of material and manpower requirements.
- An estimation of the capital and operating costs of the facilities.
- An economic analysis of the storage facility operation.

The results of this study are summarized in this section. Recommendations for future study efforts in the program of underground storage of hazardous waste are also included.

DESIGN AND OPERATING CRITERIA

The characteristics of received wastes, the storage concept, and alternative study cases are summarized below.

Waste Characterization

The hazardous wastes considered for this study are classified into four groups, each of which requires different treatment and handling. These waste types are defined as follows:

- Type A. Aqueous liquids and slurries containing dissolved hazardous elements, primarily toxic heavy metals. Type A wastes require chemical treatment before dewatering, containerization, and storage. Type A wastes include four subtypes: chromate waste (A-1), cyanide waste (A-2), acid/caustic waste (A-3), and nonreactive waste (A-4).

- Type B. Aqueous and organic sludges containing solid hazardous elements. Type B wastes require only pH adjustment and dewatering before containerization and storage. Type B wastes include acid/caustic sludges (B-1), inorganic sludges (B-2), and organic sludges (B-3).

- Type C. Inorganic and organic solids containing solid hazardous elements requiring only containerization before storage.

- Type D. Special wastes to be stored on a temporary basis at customer request. These wastes will be retrieved and sent back to the waste generator. This is included to develop cost data associated with short-term storage of the waste and its retrieval.

Storage Concept and Alternatives

Five alternative cases of waste storage were evaluated for this study. They include three plant capacities of the same hazardous waste composition (Cases 1, 2, and 3), an alternative waste composition (Case 4), and an alternative storage concept (Case 5).

The hazardous wastes brought to the plant will be treated to convert hazardous constituents to solid form, filtered to remove free fluid (water and oil), containerized (except Case 5), and finally stored in the underground storage cells for long-term storage (Figure 1). In Case 5, dewatered and deoiled hazardous wastes will be mixed with a stabilizing additive (cementing agent) and pumped into the underground storage cells without use of containers, where the mixture would be cured to form a solid mass.

In summary, the five alternative cases are:

- Case 1 (Base Case). 1,250 tons* per day of Types A, B, C, and D are received and reduced to 685 tons per day for storage in drums. Type A is treated, Types A and B are filtered, Types A, B, and C wastes are containerized.

- Case 2 (High-Capacity Case). 1,875 tons per day of Type A, B, C, and D wastes are received and reduced to 1030 tons per day for storage in drums. The waste composition, treatment, and containerization are the same as those in Case 1.

* Throughout the report British units are used for clarity. Conversion factors for these units to metric units are shown on page xi.

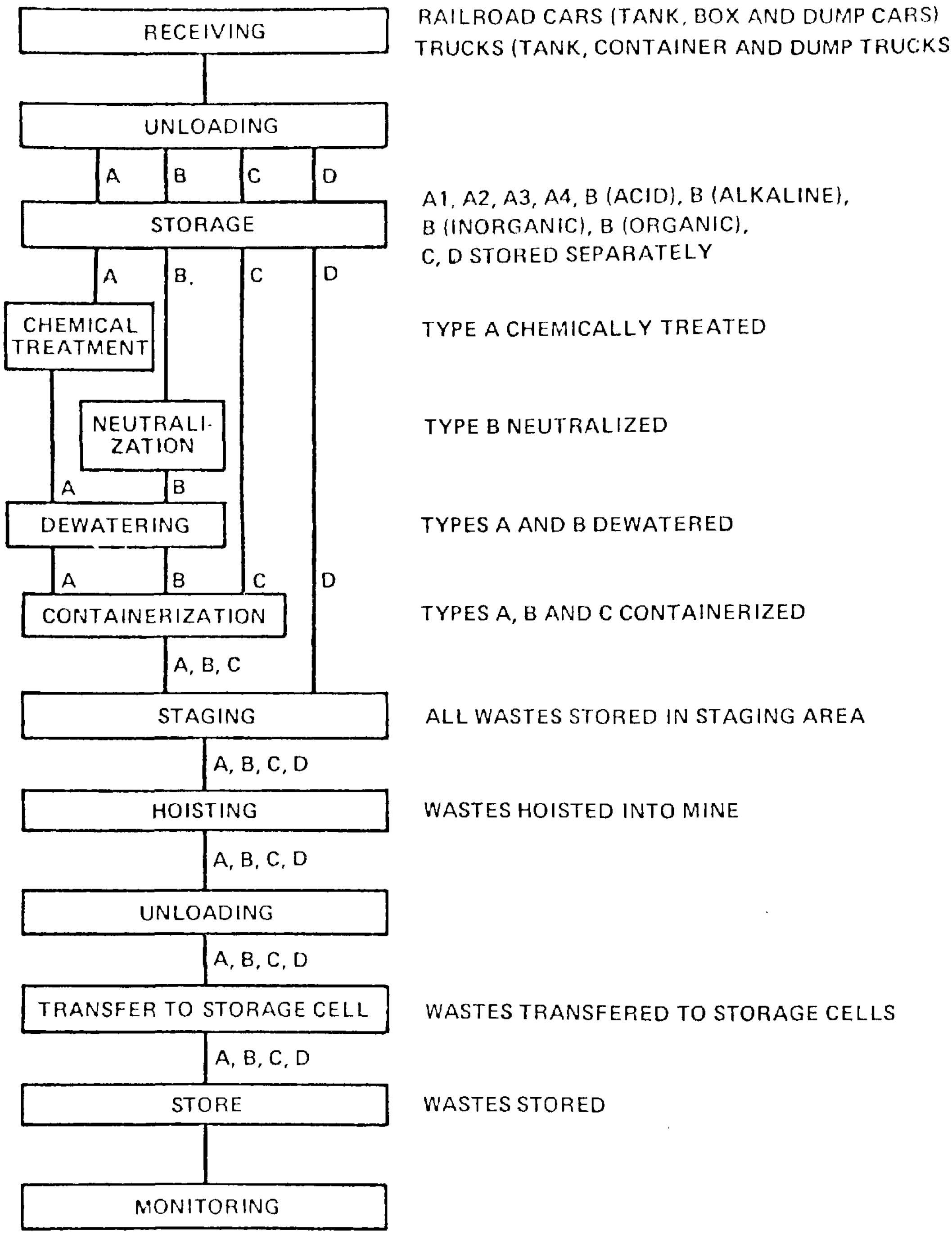

Figure 1. Storage of hazardous wastes in an underground mine--material flow chart.

- Case 3 (Low-Capacity Case). 188 tons per day of Type A, B, C, and D wastes are received and reduced to 103 tons for storage in drums. The waste composition, treatment, and containerization are the same as those in Case 1.

- Case 4 (Alternative Composition). 600 tons per day of Type B and C wastes are received and reduced to 420 tons for storage in drums. The waste composition, treatment, and containerization are the same as those in Case 1 except the absence of Types A and D.

- Case 5 (Non-Container Case). 600 tons per day of Type B and C wastes are received and reduced to 420 tons. The waste composition is the same as in Case 4. Types B and C (370 tons per day) are mixed with a stabilizing additive (11 percent cementizing agent on dry weight base) and pumped into the underground storage cells and cured to form a solid mass. 50 tons per day of Type C waste delivered in specified drums are stored directly as received and covered with cementized wastes.

FACILITY DESIGN

The surface facilities of the storage plant will consist primarily of waste treatment and material handling facilities in which received wastes are unloaded, temporarily stored, treated, containerized, and transferred to the staging area. Design information based on actual experience is not available at this time. To develop the conceptual design of the required surface facilities, numerous assumptions and simplifications had to be made concerning the waste characteristics, chemical and physical properties of the wastes at various process stages, treatability of the wastes and their intermediate products, and various reaction rates.

The conceptual design of the surface facilities presented in this report allows an order-of-magnitude cost estimation. The subsurface activity is primarily material handling and storage. Design of the subsurface facilities is based on an actual mine and its operating information. In summary, the surface facilities will include:

- Receiving and unloading facilities
- Surface facilities for temporary storage
- Treatment (chlorine oxidation, sulfur dioxide reduction, neutralization) and dewatering facilities
- Containerization and staging facilities

The subsurface facilities will include:

- Surface loading and lowering
- Underground unloading and staging
- Hauling to storage area
- Storage and monitoring

ECONOMIC EVALUATION

The capital and operating costs were estimated based on the conceptual design presented in Section 4 and on first quarter 1977 prices and wages. An economic analysis of the plant operation, including estimation of the unit cost (cost per ton) and sensitivity analysis, was performed. The capital costs were estimated based on lists and specifications of equipment, buildings, civil structures, and mine rehabilitations. The operating costs were estimated from conceptual operating plans, including a list of manpower requirements and an estimation of material requirements.

Unit Cost Per Ton (Waste Management Fee)

The unit cost per ton (waste management fee) was estimated for all five alternatives, based on the discounted cash flow net present value methodology. The unit costs were computed for private and government ownerships. The private ownership is based on a 10 percent return on investment, 100 percent equity, and 48 percent income tax, while the government ownership is based on a 100 percent financing at 6 percent cost of capital and no income tax. Results of the unit cost computation (computer calculation) are shown in Tables 16 through 26 and summarized in Tables 1 and 2.

Table 1 presents the unit costs for Cases 1, 2, and 3, which treat and store the same four waste types but at different capacities. As can be seen, plant size has significant effects on the unit cost. In the range considered, larger capacities yield lower costs. Table 2 shows the unit costs of Cases 4 and 5 and compares them with the base case costs. Cases 4 and 5 process the same two types of wastes (Types B and C), but Case 4 would containerize the waste, while Case 5 would stabilize the waste to eliminate the containers. To compare the unit costs of these different storage concepts based on the same underground storage loading, the base case unit cost was adjusted to reflect the cost at 126,000 tons per year (420 tons per day). In the case of government ownership, the Case 4 unit cost ($187 per ton stored) is almost twice of the Case 5 unit cost ($102 per ton stored). The Case 1 unit cost ($298 per ton stored) is almost three times the Case 5 unit cost. The sensitivity of plant capacity, mine cost, and cost return on investment to the unit cost were also analyzed and are presented in Section 6.

Capital Costs

The capital costs were estimated for all five cases. The capital costs include the following items:

- Existing mine facilities
- Site development
- Buildings, civil structures, and mine rehabilitation
- Equipment, piping, electrical, and instrumentation
- Engineering service, allowance during construction, and contingency

The summary of the capital costs is presented in Tables 3 and 4. Table 3 shows the capital costs for the five alternative cases. Table 4 shows the

TABLE 1. WASTE MANAGEMENT FEE
(UNIT COST PER TON)
OF ALTERNATIVE PLANT SIZES

Item	Case 1	Case 2	Case 3
Waste Quantity			
Received, tons/yr	375,000	562,500	56,250
Stored, tons/yr	205,000	309,000	30,900
Total Capital ($1000)	90,135	104,075	61,494
Economic Life (Years)	30	20	40
Waste Management Fee			
Private Ownership(1)			
$/ton of Received Waste	131	117	377
$/ton of Stored Waste	240	213	686
Government Ownership(2)			
$/ton of Received Waste	101	95	233
$/ton of Stored Waste	185	173	424

Note: (1) Private ownership assumed 10% return on investment.

(2) Government ownership assumed 6% cost of capital.

TABLE 2. WASTE MANAGEMENT FEE
(UNIT COST PER TON)
OF ALTERNATIVE STORAGE METHODS

Item	Base Case Case 1	Adjusted Case 1	Case 4	Case 5
Waste Quantity				
Received, tons/yr	375,000	229,300	180,000	180,000
Stored, tons/yr	205,500	126,000	126,000	126,000
Total Capital ($1000)	90,135	--	68,853	64,041
Economic Life (Years)	30	--	40	40
Waste Management Fee				
Private Ownership				
$/ton of Received Waste	131	210*	179	118
$/ton of Stored Waste	240	382*	257	168
Government Ownership				
$/ton of Received Waste	101	164*	131	71
$/ton of Stored Waste	185	298*	187	102

* Adjusted to reflect the cost at 126,000 tons per year (Figure 35).

TABLE 3. CAPITAL COST SUMMARY OF FIVE ALTERNATIVE CASES

Item	Base Case Case 1	Case 2	Case 3	Case 4	Case 5
	$1000's	$1000's	$1000's	$1000's	$1000's
WASTE QUANTITY					
Received Waste, Tons/Yr	375,000	562,500	56,250	180,000	180,000
Stored Waste, Tons/Yr	205,500	309,000	30,900	125,000	126,000
EXISTING MINE *	30,000	30,000	30,000	30,000	30,000
NEW SURFACE FACILITY					
Site Development	360	406	130	234	234
Buildings	5,966	7,869	2,322	3,809	2,976
Plant Utilities	560	714	370	370	370
Process Mechanical Equipment	12,428	15,435	6,064	6,287	5,136
Process Piping, Electrical & Instrumentation	8,699	11,083	4,245	4,401	3,595
DIRECT FIELD COST, SURFACE FACILITY	28,013	35,905	13,131	15,101	12,311
NEW SUBSURFACE FACILITY					
Mine Rehabilitation	1,749	1,794	1,614	1,717	1,614
New Ventilation System	4,437	4,437	2,758	4,437	4,437
Underground Buildings	231	231	111	231	231
Underground Equipment	1,812	2,354	1,208	1,812	1,778
DIRECT FIELD COST, SUBSURFACE FACILITY	8,229	8,816	5,691	8,197	8,060
TOTAL DIRECT FIELD COST	36,242	44,721	18,822	23,298	20,371
TOTAL INDIRECT FIELD COST @ 6% of TDFC	2,175	2,684	1,129	1,398	1,222
TOTAL FIELD COST	38,417	47,405	19,951	24,696	21,593
ALLOWANCE DURING CONSTRUCTION @ 1% of TFC + $500,000	884	974	699	747	716
ENGINEERING SERVICE @ 15% of TFC	5,763	7,111	2,993	3,704	3,239
CONTINGENCY @ 25% of TFC	9,604	11,851	4,988	6,174	5,398
TOTAL CONSTRUCTION COST	54,668	67,341	28,631	35,321	30,946
WORKING CAPITAL @ 10% of TCC	5,467	6,734	2,863	3,532	3,095
TOTAL INVESTMENT	90,135	104,075	61,494	68,853	64,041
$/Ton Received	240	185	1,093	383	356
$/Ton Stored	439	337	1,990	551	508

NOTE: Number of significant figures may exceed those justified by accuracy of the estimate.

*See page 107

TABLE 4. CAPITAL COST SUMMARY OF BASE CASE AND ITS ALLOCATION TO TYPES A, B, C, AND D WASTES

Item	BASE CASE (CASE 1)				
	Total	Type A	Type B	Type C	Type D
	$1000's	$1000's	$1000's	$1000's	$1000's
WASTE QUANTITY					
Received Waste, Tons/Yr	375,000	180,000	120,000	60,000	15,000
Stored Waste, Tons/Yr	205,500	64,500	66,000	60,000	15,000
EXISTING MINE COST *	30,000	8,775	8,979	8,163	4,083
NEW SURFACE FACILITY COST					
Site Development	360	166	111	55	28
Buildings	5,966	2,656	1,837	1,052	421
Plant Utilities	560	332	162	53	13
Process Mechanical Equipment	12,428	6,646	4,118	1,522	142
Process Piping, Electrical & Instrumentation	8,699	4,652	2,882	1,065	100
DIRECT FIELD COST, SURFACE FACILITY	28,013	14,452	9,110	3,747	704
NEW SUBSURFACE FACILITY COST					
Mine Rehabilitation	1,749	512	523	476	238
New Ventilation System	4,437	1,298	1,328	1,207	604
Underground Buildings	231	68	69	63	31
Underground Equipment	1,812	530	542	493	247
DIRECT FIELD COST, SUBSURFACE FACILITY	8,229	2,408	2,462	2,239	1,120
TOTAL DIRECT FIELD COST	36,242	16,860	11,572	5,986	1,824
TOTAL INDIRECT FIELD COST @ 6% of TDFC	2,175	1,012	694	359	110
TOTAL FIELD COST	38,417	17,872	12,266	6,345	1,934
ALLOWANCE DURING CONSTRUCTION @ 1% of TFC + $500,000	884	412	283	145	44
ENGINEERING SERVICE @ 15% of TFC	5,763	2,681	1,840	952	290
CONTINGENCY @ 25% of TFC	9,604	4,468	3,067	1,586	483
TOTAL CONSTRUCTION COST	54,668	25,433	17,456	9,028	2,751
WORKING CAPITAL @ 10% of TCC	5,467	2,543	1,746	903	275
TOTAL INVESTMENT	90,135	36,751	28,181	18,094	7,109
$/Ton Received	240	204	235	302	474
$/Ton Stored	439	570	427	302	474

NOTE: Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

* See page 107

base case capital cost and its allocation to the waste types (Types A, B, C, and D) subjected to different treatments and handlings. Distribution of the base case capital cost to the waste types reflects only relative cost for each waste type and does not imply that each waste type alone will cost the indicated figure.

Operating Costs

The operating costs were estimated for all five cases. The operating costs include the costs of:

- Direct material and labor
- Maintenance material and labor
- Overhead material and labor
- Taxes and insurance, depreciation, and long-term liability insurance

The summary of the operating costs is presented in Tables 5 and 6. Table 5 shows the operating cost of the five alternative cases. Table 6 shows the operating cost of the base case and its allocation to the waste types, which are being subjected to different treatments and handlings. As in the capital cost allocation to the waste types, the allocation of the operating cost reflects only the relative operating cost of each waste type and does not imply that any one waste, alone, can be stored at the indicated cost. The operating cost per ton shown at the bottom of Tables 5 and 6 does not include the cost of capital and depreciation (and should not be confused with the unit cost, cost per ton waste management fee computed by discounted cash flow methodology).

RECOMMENDATIONS

Based on the findings of this study, the following studies are believed essential for establishing an effective underground hazardous waste storage program:

(1) Development of a better storage concept than that used in the base case -- direct emplacement of stabilized (cementized) hazardous wastes.

(2) Development of inexpensive waste containers.

(3) Identification and characterization of hazardous wastes suited for the subsurface storage.

Development of Better Storage Concepts

As indicated in the cost summary (Table 6), the direct storage of hazardous waste (mixing the waste with a cementizing agent and pumping it into the underground storage cell where it is cured and converted to a solid mass filling the entire space) is economically most attractive. However, the stabilization (cementizing) of hazardous waste is still in the development stage and requires further research and development efforts.

TABLE 5. OPERATING COST SUMMARY OF FIVE ALTERNATIVE CASES[1]

Item	Base Case Case 1	Case 2	Case 3	Case 4	Case 5
	$1000's	$1000's	$1000's	$1000's	$1000's
WASTE QUANTITY					
Received Waste, Tons/Yr	375,000	562,500	56,250	180,000	180,000
Stored Waste, Tons/Yr	205,500	309,000	30,900	126,000	126,000
TOTAL CAPITAL COST	90,135	104,075	61,494	68,853	64,041
DIRECT OPERATING COST					
RAW MATERIALS & UTILITIES					
Chemicals	1,526	2,297	230	55	275
Drums & Pallets	13,395	20,093	2,009	8,225	0
Utilities	1,907	2,724	352	923	773
	16,828	25,114	2,591	9,203	1,048
DIRECT LABOR					
Operating Labor (2)	3,695	4,860	1,323	2,533	1,658
MAINTENANCE					
Labor	1,565	1,908	478	1,379	914
Materials	3,643	4,616	1,843	2,021	1,721
	5,208	6,524	2,321	3,400	2,635
INDIRECT OPERATING COST					
ADMINISTRATION & GENERAL OVERHEAD					
Labor	1,486	1,889	534	1,026	735
Materials	337	433	117	247	165
	1,823	2,322	651	1,273	900
FIXED COST(3)					
TAXES AND INSURANCE(3)					
@ 2% of Plant Cost and $1.10 per ton for Long Term Liability Insurance	2,215	2,700	1,292	1,575	1,479
OPERATING COST (4)	29,769	41,520	8,178	17,984	7,720
$/Ton Received (4)	79	74	145	100	43
$/Ton Stored (4)	145	134	265	143	61

NOTE: (1) Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

(2) Labor costs include 30% payroll additive and 8% overtime compensation.

(3) Insurance includes $1.10 per ton (0.5¢/gallon) of received waste for Long Term Liability and other insurances.

(4) Cost of Capital and depreciation is not included.

TABLE 6. OPERATING COST SUMMARY OF THE BASE CASE AND ITS ALLOCATION TO TYPES A, B, C, AND D WASTES(1)

Item	BASE CASE (CASE 1)				
	Total $1000's	Type A $1000's	Type B $1000's	Type C $1000's	Type D $1000's
WASTE QUANTITY					
Received Waste, Tons/Yr	375,000	180,000	120,000	60,000	15,000
Stored Waste, Tons/Yr	205,500	64,500	66,000	60,000	15,000
TOTAL CAPITAL COST	90,135	36,751	28,181	18,094	7,109
DIRECT OPERATING COST					
RAW MATERIALS & UTILITIES					
Chemicals	1,526	1,471	55	0	0
Drums & Pallets	13,395	4,934	5,030	3,431	0
Utilities	1,907	1,146	527	160	74
	16,828	7,551	5,612	3,591	74
DIRECT LABOR					
Operating Labor (2)	3,695	1,498	1,218	715	264
MAINTENANCE					
Labor	1,565	574	474	345	172
Materials	3,643	1,859	1,191	502	91
	5,208	2,433	1,665	847	263
INDIRECT OPERATING COST					
ADMINISTRATION & GENERAL OVERHEAD					
Labor	1,486	652	456	252	126
Materials	337	137	103	65	32
FIXED COST	1,823	789	559	317	158
TAXES & INSURANCE (3)					
(@2% of plant cost and $1.10 per ton for Long Term Liability Insurance)	2,215	933	696	428	158
OPERATING COST (4)	29,769	13,204	9,750	5,898	917
$/Ton Received (4)	79	73	81	98	61
$/Ton Stored (4)	145	205	148	98	61

NOTE:

(1) Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

(2) Labor rate includes 30% payroll additive (fringe benefits) and 8% overtime compensation.

(3) Insurance includes $1.10 per ton (0.5¢/gallon) of received waste for Long Term Liability and other insurance.

(4) Cost of Capital and Depreciation is not included.

There have been several studies (Ref. 2, 3 and 4) on stabilization of hazardous wastes to convert the waste into an insoluble or very low soluble form. However, past studies have generally emphasized the development of a solid with a minimal leachate problem. Most of the available data, therefore, are the results of various leaching tests. Interests in the waste stabilization associated with underground waste storage are somewhat different from those associated with the surface land disposal. That is, for underground storage, handling and engineering properties are more important, while for surface land disposal, the primary concern is leaching of hazardous constituents.

Although its economic attractiveness has been demonstrated, further technical evaluations are required to confirm the feasibility of storing hazardous waste in mines without containers. Major objectives of such a study should include:

- Finding proper stabilization additive
- Finding optimum additive dosage
- Development of various process design criteria
- Development of engineering data of the mixture at the various process stages

Some of the specific questions needed to be answered to confirm the technical feasibility of the concept are:

- Can the cured mass be used to form a dike of a few feet to retain the wet mixture during the curing process?
- Can the cured mass support heavy equipment?
- Can the mixture be pumped?

Development of Inexpensive Waste Containers

The 55-gallon, 16 gauge steel drum container was selected for this study because its use is proven technology; however, at $22 each, the drum cost is over $70 per ton of the stored waste. Less expensive containers may be feasible, such as a heavy duty wood box with plastic lining. Use of a wood box, however, will require testing for applicability. If the containerization of the waste were to be practiced, use of a container other than a steel drum should be explored. Testing for applicability of a container may include tests for structural integrity (drop test, puncture test, compression test, etc.) handleability, and resistance to corrosion, fire, and shear.

Identification and Characterization of Waste to Be Stored

Not all hazardous wastes are suited for underground storage. Some of the wastes considered hazardous may be better incinerated, while some of the others may be disposable in a secured surface landfill.

In many parts of the country, finding a secured on-land disposal site for hazardous wastes is a very difficult problem and underground mine space can be very attractive for hazardous waste management. Underground mine space is a valuable resource and should not be misused by storing wastes that could be readily disposed of by other means.

Presently, the characteristics of hazardous wastes are poorly defined, and their quantities are not well inventoried. However, investigations are in progress in several states to develop pertinent data, which should be available within a year. This information should be reviewed to define:

- A list of hazardous wastes suited for underground storage. This may depend on the specific mine in the given region.
- The characteristics of the wastes to be stored as they are generated at the source and as they are received at the plant.

Section 3

DESIGN BASIS OF THE STUDY

This section presents the design basis of this study, including descriptions of the quantity and characteristics of the wastes to be stored, the methodologies of waste treatment, handling, and storage, and the physical requirements of the storage site. A brief description of the methodology used in selecting the actual subject mine is presented, along with a detailed description of the mine itself. The selected mine is a typical room and pillar salt mine in a bedded salt deposit, but specific information that would reveal its name and location has been avoided.

The only known practice of underground storage of hazardous wastes is at Herfa-Neurode in West Germany. At the present time, that operation is a simple storage facility without treatment or recontainerization of received wastes. No attempt is made to convert the wastes to a more stable form. The operation is gradually improving through trial and error. It was decided that although the German experience is valuable for this study, a fresh approach based on the trend of U.S. waste management practices would be developed.

The characteristics of hazardous wastes to be received at the storage plant were formulated based on the current U.S. hazardous waste management practice and its potential changes. The characteristics of stored wastes were developed based on the concept of long-term environmental protection and the use of the best practical technology in the treatment and handling of the received wastes.

WASTE CHARACTERISTICS AND QUANTITY

In the report to Congress on hazardous waste disposal by the U.S. EPA (Ref. 5) June 30, 1973, the hazardous waste is defined as:

> "Any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are lethal, undegradable, persistent in nature, biologically magnified, or otherwise cause or tend to cause detrimental cumulative effects. General categories of nonradioactive hazardous waste are toxic chemicals; flammable, explosive and biological. These wastes can take the form of solids, sludges, liquids, or gases."

In an attempt to determine the characteristics and quantities of hazardous wastes to be handled at the storage plant, a series of reports (Ref. 6 through 11) issued on the studies of the National Disposal Site concept, and the reports (Refs. 12 through 24) on the Assessment of Industrial Hazardous Waste Practices have been reviewed. In addition, the reports (Refs. 25 through 28) on hazardous waste management practice in the State of California were also reviewed.

It is apparent from these reports that the characteristics of hazardous wastes are not well identified, and their quantity and source distribution have not yet been inventoried. It is recognized that the characteristics and quantities of hazardous wastes will change considerably in the near future, governed by many complex and uncertain factors, including:

- Local and state hazardous waste management programs
- Federal regulations on hazardous waste management to be promulgated under the Resource Conservation and Recovery Act of 1976
- Changes in manufacturing and waste treatment processes
- Location of storage (or disposal) site
- Criteria of design and operation of disposal (or storage) facility

The majority of hazardous wastes in the United States is generated by industry. Due to the differences in the manufacturing processes, local law, and availability of disposal sites, the characteristics and quantities of hazardous wastes differ from plant to plant in a given industry. Even for a given plant, waste characteristics and quantities are expected to change as new regulations and standards are enforced.

At present, hazardous waste management practices (generation, transportation, treatment, and disposal) are controlled at the state level. However, the Resource Conservation and Recovery Act of 1976 (Public Law 94-580) makes hazardous waste management a federal responsibility. Many new regulations and standards controlling hazardous waste management are to be promulgated before April 21, 1978. The Act also requires the U.S. EPA to develop and promulgate criteria for identifying the characteristics of hazardous wastes and for listing hazardous wastes before April 21, 1978.

As in the case of the wastewater management practice under the Federal Water Pollution Control Act of 1972, each state is expected to develop a hazardous waste management program in lieu of the federal program and will be authorized to issue and enforce permits for storage, treatment, and disposal of hazardous wastes. Because of the strong dependence of hazardous waste disposal on local climatic and geological conditions, different states may have different approaches to the disposal of hazardous wastes. Accordingly, industrial plants of the same type in different states may be required to handle their hazardous waste differently and produce chemically and physically different wastes.

The reports on the Assessment of Industrial Hazardous Waste Practices (Refs. 12 through 24) showed an approximate estimate of various hazardous waste quantities. This is summarized in Appendix A.

As shown in Appendix A, the quantities and characteristics of hazardous wastes vary considerably from state to state and region to region, depending on their industrial distribution. An extensive survey will be required to inventory the sources and to determine accurately the quantity presently generated in any given region. The State of California has just started such an inventory of the statewide hazardous waste sources and their characteristics.

The cost of storing these hazardous wastes will also affect the quantities and characteristics of the waste received at the storage plant. Disposal or reprocessing at the industrial source eliminates transportation cost, and some industries may find this advantageous. This would eliminate or reduce the need for storing the hazardous wastes at the storage plant.

The storage of hazardous wastes in underground mines generally requires chemical and physical treatment of these hazardous wastes to reduce the volume or to convert to more stable form. The majority of known hazardous wastes are a mixture of many compounds, and the hazardous constituents are usually a very minor portion of the total waste. Thus, both treatment and storage techniques are dictated as much or more by the nonhazardous components as by the hazardous constituents.

From these considerations, it was decided that the waste characteristics to be used for this study should be of a general nature reflecting a wide range of waste types and their possible change with time, but also specific enough to reveal different handling requirements.

For this study, hazardous wastes were classified into groups that would be subjected to similar treatment and handling during their receiving and unloading, chemical treatment, dewatering, containerization, stabilization, and storage.

Waste Characteristics Selected for the Study

Hazardous wastes to be handled at the storage site are classified into four types. In formulating the waste classification, the following general criteria were considered:

- All known hazardous wastes should be included except those which cannot be stored because of their volatility and explosiveness.
- Waste should be classified into groups that will be representative of the current hazardous wastes and future changes as new regulations are enforced.
- Wastes should be classified according to the needs of common treatment and handling so that appropriate costs will be charged to the customers storing different wastes.
- Possible alternative modes of waste storage operation should be considered in the waste classification.

The classification of hazardous wastes into four types and further grouping of each type into subgroups was not intended to represent the true and accurate classification of what might be handled at a centralized hazardous waste storage plant, but only to represent a reasonable classification to allow development of realistic cost information for handling different types of hazardous wastes.

The classification of hazardous wastes into different types, each being subject to specific treatment and handling, also provides the EPA with comparative cost information that will be useful in their future pursuits and planning of the underground storage concept.

Hazardous wastes to be stored in the underground storage facility are classified into the following four types.

- Type A, aqueous liquids and slurries
- Type B, aqueous and organic sludges
- Type C, inorganic and organic solids
- Type D, special liquid and solid wastes requiring retrieval

Type A, Aqueous Liquids and Slurries. Type A includes liquid and slurry hazardous wastes requiring chemical treatment followed by precipitation, dewatering, and containerization. This type of hazardous waste contains toxic inorganic constituents, primarily heavy metals such as cadmium, copper, zinc, lead, mercury, nickel, manganese, arsenic, antimony, selenium, and beryllium.

Concentrated liquid waste such as spent plating solution from an electroplating industry is a typical example of this type waste. Currently, many industries producing this type of hazardous waste use the services of small private hazardous waste management firms that haul these wastes to collective treatment or disposal sites.

Type A wastes are further divided into four subgroups requiring different treatments:

- Type A-1, Chromate Waste. Wastes containing hexavalent chromium, which requires sulfur dioxide (SO_2) reduction before precipitation of heavy metals and subsequent dewatering.
- Type A-2, Cyanide Waste. Wastes containing cyanides, which require chlorine (Cl_2) oxidation before precipitation of heavy metals and subsequent dewatering.
- Type A-3, Acidic and Caustic Liquids and Slurries. Liquid and slurry wastes requiring neutralization before precipitation of heavy metals and dewatering.
- Type A-4, Nonreactive Mixed Waste. Liquid and slurry wastes containing heavy metals, requiring only precipitation and dewatering.

A likely composition of Type A wastes, shown in Table 7, was approxi-

TABLE 7. COMPOSITION OF HAZARDOUS LIQUID AND SLURRY WASTES *

Type A-1 Chromate Wastes (lbs/Day)		Type A-2 Cyanide Wastes (lbs/Day)		Type A-3 Acid/Caustic Wastes (lbs/Day)				Type A-4 Non-Reactive Wastes (lbs/Day)	
CrO_3	5,000	NaCN	5,000	HCl	5,000	NaOH	8,000	NaCl	10,000
H_2SO_4	5,000	NaOH	10,000	H_2SO_4	5,000	Na_2CO_3	2,000	$CaCl_2$	13,000
HCl	1,000	Na_2CO_3	3,000	HNO_3	1,000	M(OH)x	8,000	$M(SO_4)x$	17,000
$M(SO_4)x$**	4,500	M(Cl)x	7,700	H_3PO_4	1,000	SiO_2	1,000	H_2O	360,000
Organics	500	H_2O	174,300	$M(SO_4)x$	22,800	Organics	3,000		
H_2O	184,000			Organics	500	H_2O	178,000		
				H_2O	164,700				
	200,000		200,000		200,000		200,000		400,000

*This is an approximate waste composition used to compute the chemical requirement in Type A waste treatment of Base Case.

**M refers to metal ions including hazardous constituents.

mated from the characteristics of hazardous liquid wastes presently being received by established hazardous waste management firms (Ref. 9). The composition is not intended to represent a true average of what might be received at the storage plant, but only reflects a realistic approximation used for carrying out this study.

Sources of Type A wastes may include small electroplating industries, textile industries, tanneries, electronic component manufacturers, and others who find it advantageous to send their liquid and slurry wastes (concentrated wastewaters) to underground storage sites.

Type B, Aqueous and Organic Sludges. Type B wastes include hazardous sludge wastes, requiring only dewatering and pH adjustment (B-1) before containerization and storage. Toxic sludges from industrial wastewater treatment plants are typical of this type hazardous waste. Type B wastes are subdivided into acid/caustic sludge (B-1), inorganic sludge (B-2), and organic sludge (B-3) for the purpose of separate handling and separate storage.

The sources of inorganic sludges include battery industries, inorganic chemical industries, metal smelting and refining industries, electroplating industries, and machine manufacturing industries. The source of sludges containing toxic organic residue and organic solvents includes organic chemical industries, paint and allied product industries, pharmaceutical industries, and rubber and plastic industries. Some of these sludges (B-1) will be either acidic or caustic when received at the storage plant and will require neutralization.

Type C, Inorganic and Organic Solids. Type C wastes include those hazardous solid wastes requiring no treatment and no dewatering prior to containerization. Type C wastes may be the same wastes as Type B, except they are dewatered. Toxic solid wastes such as rejected battery products and pesticide containers are also included in this type of hazardous waste. Some of Type C wastes will be delivered to the storage plant already containerized. Type C wastes delivered in bulk quantity will be containerized before the underground storage.

Type D, Special Waste for Retrieval. Type D includes hazardous wastes brought to the plant for temporary storage. These wastes will be stored for a given period and retrieved to be returned to the owner. These wastes will be delivered to the site containerized in specified containers, which will maintain their integrity during storage. Type D waste was included in this study only to obtain cost information on the retrieval operation. Inclusion of Type D waste does not imply that this operation is recommended, nor likely to occur at an actual storage plant.

PLANT CAPACITIES

Determination of the plant capacity based on actual market conditions of the storage service was impossible at this time.

Hazardous waste of 1,250 ton per day (TPD) capacity (as received) was selected as the base case (Case 1) for this study. This represents approximately 685 TPD of hazardous waste stored in the underground mine after de-watering. The 685 TPD capacity selected for the base case represents the capacity of the existing hoisting system during normal two-shift operation of the selected salt mine facility.

To evaluate the sensitivity of plant capacities on the design of the storage facility and the capital and operating costs, two additional plant capacities -- one higher and one lower than the base case -- were also included in the study. The high-capacity case (Case 2) receives 1,875 TPD of hazardous wastes and stores 1,030 TPD, while the lower capacity case (Case 3) receives 188 TPD and stores 103 TPD. The proportions of the Type A, B, C, and D wastes in Case 2 and Case 3 are the same as that of the base case.

The 1,030 TPD storage (Case 2) represents an upper limit based on three-shift operation of the existing hoisting system operated at 75 percent of the design capacity. The 103 TPD storage (Case 3) represents a low capacity of one-shift operation of all underground facilities.

The quantities of Type A, B, C, and D wastes received and stored for Cases 1, 2, and 3 are shown in Table 8. The proportions of Type A, B, C, and D wastes shown in Table 8 were selected to study the sensitivity of the waste types on design of the plant facility and the capital and operating costs. For the base case, approximately equal storage loadings (215 TPD, 220 TPD, and 200 TPD) were selected for the Type A, B, and C wastes, respectively. This includes 65 TPD and 20 TPD of solids resulting from evaporation of Type A waste filtrates and Type B waste filtrates. The 50 TPD loading of Type D waste was selected to develop cost data for a small but reasonable retrieval operation in conjunction with the long-term storage of Type A, B, and C wastes. Cases 4 and 5, shown in Table 8, are for different modes of operation than Cases 1, 2, and 3, as discussed in the following section.

WASTE STORAGE CONCEPT

General criteria considered in formulating the concept of storing hazardous wastes in salt mine openings are as follows:

- Waste storage will be long-term storage without planned retrieval of stored waste, except certain types of waste that may be stored temporarily.
- Retrieval of the long-term stored waste will be considered only when an extreme emergency occurs and no other alternative is available.
- To assure the long-term environmental protection and to prevent the need of retrieving the long-term stored waste, all wastes brought to the plant will be converted to the most stable chemical and physical forms using the best practical technology.
- The stored waste will not contain any substance that could generate toxic fumes, fire, hazardous vapor, or explosive material.
- The storage operation will include all activities

TABLE 8. WASTE COMPOSITION OF ALTERNATIVE CASES

	Case 1	Case 2	Case 3	Case 4	Case 5
Type A, TPD Received	600	900	90	0	0
TPD Stored	150	225	22	0	0
Type B, TPD Received	400	600	60	400	400
TPD Stored	200	300	30	200	200
Type C, TPD Received	200	300	30	200	200
TPD Stored	200	300	30	200	200
Type D, TPD Received	50	75	8	0	
TPD Stored	50	75	8	0	
Solids From Wastewater Evaporation, TPD Stored	85*	130	13	20	20
Total Received	1250	1875	188	600	600
Total Stored	685	1030	103	420	420

*85 TPD wastewater solids include 65 TPD from Type A and 20 TPD from Type B wastes.

from waste receiving at the gate to waste emplacement in underground storage cells. Transport to the plant site is not included in this study, except formulating reasonable modes of transport methods.

- All wastes brought to the plant will be stored, except the clean condensate from the filtrate evaporation.
- There will be no effluent from the plant, except sanitary wastewater and clean runoffs.
- The selected storage method will provide long-term environmental protection without perpetual maintenance of the stored materials.
- The selected storage method will use the available space effectively.
- The stored material will be inventoried to identify the waste type, quantity, and storage location, in case retrieval becomes necessary.

These criteria dictate that hazardous wastes brought to the plant have to be treated to precipitate any dissolved hazardous constituents and then dewatered. In addition, if the waste contains a component that may generate toxic fumes, the waste must be treated to remove or destroy the component. Cyanide, for example, must undergo chloride oxidation followed by lime precipitation and filtration.

The criteria also dictate that the waste cannot be disposed of indiscriminately into mine openings, but it has to be stored in a systematic manner to allow controlled handling, segregated storage of different wastes, short-term maintenance of stored waste, inventorying of the stored waste, and long-term protection of the environment. To meet these criteria, it was decided to containerize the wastes in all study cases, except Case 5, in which the waste is cementized instead of containerized.

The container should be a type that can be readily obtained and suited for the required handling. The container should also be a type that can be stacked to an average of 21 feet. It was concluded that for this study, open-top, 16 gauge, epoxy-lined 55-gallon steel drums will be used for containerization of all wastes.

In summary, the waste received at the storage plant will be treated to convert hazardous elements into relatively insoluble forms, then filtered to remove free water, and finally containerized in 55-gallon steel drums. The waste in steel drums will then be hoisted into the mine on pallets, each containing four drums. The pallets will be transferred to the storage cell where they will be stacked to an average height of 21 feet. Details of the design and operation are included in Section 4.

ALTERNATIVE STORAGE CONCEPTS

During the course of this study, it became apparent that Type A waste requires a complicated and extensive chemical treatment facility. In fact, proper handling of Type A waste would make the facility resemble a waste treatment operation more than a storage operation.

To evaluate the concept of receiving only non-liquid (residue) types of hazardous wastes, a special case (Case 4) where only Type B and C wastes are handled is included in this study. Operation of Case 4 will be the same as that of the base case, except that it would require no chemical treatment and thereby would reduce the surface activity considerably.

It also became apparent that the container cost will be a major item of the overall operating cost, and any storage method that eliminates the need of containerization would be very attractive.

To explore the possibility of eliminating containerization, several presently available waste stabilization methods (solidification) were reviewed and one of these stabilization methods (Case 5) is included in this study. In Case 5, the non-liquid wastes (Types B and C) will be dewatered, mixed with a stabilizing additive, and then pumped into the storage cell area in the mine. Details of these alternative cases (Cases 4 and 5) are included in Section 4. The types of waste received and stored, and concepts of the five different cases are summarized in Table 9.

MINE SELECTION AND DESCRIPTION OF SELECTED MINE

Mine Selection

One of the study tasks was to examine and evaluate existing salt mines to select one specific typical salt mine suitable for the storage of hazardous waste. The selected mine was used as a base from which design and cost information was obtained. To prevent potential adverse public reaction, the study mine has not been identified. Due to the limited time and budget, the selection procedure was to be based on readily available information without actual site surveys of the mines being considered. A summary of the mine selection procedures and a description of the selected mine are presented below.

In the EPA technical assessment report, 17 salt mines were identified. In this study, all 17 were evaluated to select a typical salt mine suitable for waste storage. The selection of the study mine involved a two-step evaluation: (1) screening of the mines based on general non-geologic selection criteria and (2) final selection based on specific geologic criteria. These two criteria groups are as follows:

- General Criteria (physical, social, and economic factors):

    1. Suitability of mine (availability of suitable space)
    2. Availability of information (maps and design information)
    3. Availability of surface land
    4. Distance to waste source
    5. Accessibility to mine
    6. Compatability with other resource development (oil, gas, coal, etc.)

TABLE 9. LOADING AND TREATMENT SUMMARY OF ALTERNATIVE STUDY CASES

	Waste Received TPD	Waste Stored TPD	Storage Concept
Case 1	1250	685	Type A treated, Types A&B filtered, Types A, B &C containerized, Types A, B, C &D stored.
Case 2	1875	1030	Same as Case 1, except total plant capacity.
Case 3	188	103	Same as Cases 1 and 2, except total plant capacity.
Case 4	600	420	Same as Case 1 except, Types A & D are not included.
Case 5	600	420	Same as Case 4 except waste is stabilized (cementized) and stored directly into mine space.

- Specific Criteria:

  1. Dryness of mine
  2. Imperviousness of associated seams
  3. Isolation from aquifers
  4. Structural stability of mine
  5. Reactivity of mineral
  6. Homogeneity of mineral
  7. Seismicity of area
  8. Faulting of area
  9. Competence and strength of mine
  10. Alteration and dissolution of mineral
  11. Depth of mine
  12. Inclination of seam
  13. Erosion potential
  14. Thickness of seam
  15. Distribution of seam
  16. Relief
  17. Access to mine
  18. Glaciation
  19. Inundation

The above criteria are those suggested in the technical assessment report. The mine evaluation was based on Bechtel information and staff experience of the subcontractor, a large salt producing company, together with informal contacts with salt industry personnel. It should be recognized that the mine selection procedure used in this study is of a preliminary nature. Much more information based on actual survey data will be required if actual selection of storage sites were to be carried out. The results of the evaluation are summarized based on general criteria in Table 10 and based on specific criteria in Table 11.

In the mine screening process, rating scales of favorable (F), marginal (M), unacceptable (U), and not determined (X) were used for both general and specific criteria evaluation. In the general criteria evaluation, a mine receiving an unfavorable rating in any category was eliminated from further consideration. All mines with more than one marginal classification were provisionally eliminated from consideration, to be considered only if all other mines were later eliminated. Table 10 summarizes the results of this initial evaluation.

The eight mines remaining after the general criteria evaluation were further considered in the second evaluation step based on the specific geologic criteria. As in the initial screening, all mines with an unfavorable rating were eliminated from further consideration, and those with more than two marginal ratings were provisionally eliminated. Table 11 summarizes the results of the evaluation of the eight mines based on the specific criteria.

The three mines (Mines No. 2, 7 and 14) not eliminated at this point were considered acceptable for storing hazardous waste. All three remaining mines are of room and pillar type. Mines No. 2 and 7 are of bedded salt, while Mine No. 14 is of dome salt. Any one of the three mines could have

TABLE 10. EVALUATION OF CANDIDATE MINES BASED ON GENERAL CRITERIA

General Criteria	Mine Number																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Suitability of Mine	M	F	F	X	F	F	F	F	X	X	X	X	F	F	X	X	X
Availability of Information	M	F	M	M	F	F	F	F	U	U	U	U	M	M	U	M	M
Availability of Surface Land	X	F	F	X	F	F	F	F	X	X	X	X	F	F	X	X	X
Distance to Waste Sources	F	F	F	M	F	F	F	F	F	F	F	F	F	F	U	M	M
Accessability	X	F	F	X	F	F	F	F	X	X	X	X	F	F	X	X	X
Compatability with Other Resource Development	X	F	F	X	F	F	F	F	X	X	X	X	F	F	X	X	X
Summary	M	F	F	M	F	F	F	F	U	U	U	U	F	F	U	M	M

F = Favorable M = Marginal U = Unacceptable X = Not Determined

TABLE 11. EVALUATION OF CANDIDATE MINES BASED ON SPECIFIC CRITERIA

Specific Criteria	Mine Number 2	3	5	6	7	8	13	14
1. Dryness of Mine	F	F	F	M	F	M	F	F
2. Imperviousness	M	M	F	M	F	F	M	F
3. Isolation	F	M	F	F	F	F	M	F
4. Structural Stability	F	F	F	F	F	M	F	F
5. Reactivity of Mineral	F	F	F	F	F	F	F	F
6. Homogeneity of Mineral	F	F	F	F	F	F	F	F
7. Seismicity of Area	F	F	F	F	F	F	F	F
8. Faulting of Area	F	M	M	M	F	F	M	F
9. Competence & Strength	F	F	F	F	F	F	F	F
10. Alteration & Dissolution	F	F	F	F	F	F	F	F
11. Depth of Seam	F	F	F	F	F	F	F	F
12. Inclination of Seam	F	F	F	F	F	F	F	F
13. Erosion Potential	F	F	F	F	F	F	F	F
14. Thickness of Seam	F	F	F	F	F	F	F	F
15. Distribution of Seam	F	F	F	F	F	F	F	F
16. Relief	F	F	F	F	F	F	F	F
17. Access to Mine	F	F	F	F	F	F	F	F
18. Glaciation	M	F	M	F	M	M	F	F
19. Inundation	F	M	M	M	F	M	M	F
Summary	F	M	M	M	F	M	M	F

F = Favorable M = Marginal U = Unfavorable been selected as a typical salt mine acceptable for the storage of hazardous waste; however, Mine No. 7 had the most available information, and with the approval of the EPA Project Officer, Mine No. 7 was selected for the study.

General Description of Selected Mine

All mine design and economic information used in this study is based on an actual mine selected for this study. To prevent potential adverse public reaction, the study mine is not identified and an effort was made to modify the mine description so that the identity of the mine would not be revealed. However, the modification of the mine description is so handled that important characteristics of the selected mine are accurately described.

Geology --

The geology of bedded salt deposits is adequately discussed elsewhere (Ref. 1). To provide a reference for understanding the geology of the waste storage site, a brief description of the geology of the Michigan Basin and of a salt mine operating in the basin is presented. This should be treated as background data and is not site specific to the study.

The general character of the geologic province is that of a basin typically covered with a thick blanket of glacial drift. Rock units from each division of the Paleozoic era, Cambrian through Pennsylvanian, are represented as shown in Table 12. These layers, representing the various Paleozoic divisions, are situated in the basin similar to a stack of spoons of decreasing size (see Figure 2).

Mining occurs in the Salina group of the Silurian Period. This sequence of carbonate, shale, and evaporite rock is divided into a series of formations (Table 12). Although numerous salt units are included in these formations, only one is presently mined. A stratigraphic column of the shaft area of an operating mine located in the Michigan Basin is shown in Figure 3.

In the basin itself, there are extensive oil and gas bearing rocks both above and below the Salina. The bulk of the oil has come from carbonate rocks of the Devonian period, with less amounts from Ordovician and Silurian carbonates. Most gas production as been from Mississippian sandstones and to some extent from Ordovician and Silurian carbonates.

Hydrological --

The unconsolidated overburden of glacial drift ranges from 80 to 120 feet thick in the vicinity of the mine. The drift is primarily clay with thin and limited sand and gravel horizons. Water yields are small, quite hard, sulfurous, and often gassy (hydrogen sulfide). The rock units immediately below the glacial drift are heavy water producers. A water bearing sandstone at the 550 to 650 foot level would require special attention in terms of shaft grouting. Shaft sinking through these zones has experienced water problems, which, while not insurmountable, have slowed progress and escalated costs.

TABLE 12. GENERAL STRATIGRAPHIC SECTION OF THE MICHIGAN BASIN

SYSTEMS, SERIES	FORMATION, GROUP	LITHOLOGY	THICK-NESS
PLEISTOCENE	Glacial Drift	Sand, Gravel, Clay, boulder, marl	0-1000
PERMO-CARBONIFEROUS	Red-Beds	Shale, Clay, Sandy Shale, gypsum	
PENNSYLVANIAN	Grand River	Sandstone, sandy, shale	80-95
	Saginaw	Shale, Sandstone, limestone, coal	20-535
MISSISSIPPIAN	Bay Port	Limestone, Sandy or Cherty Limestone, Sandstone	2-100
	Michigan	Shale, gypsum, anhydrite, sandstone	0-500
	Michigan Stray	Sandstone	0-80
	Marshall	Sandstone, sandy shale	100-400
	Coldwater	Shale, sandstone, limestone	500-1100
	Sunbury	Shale	0-140
	Berea-Bedford	Sandstone, Shale	0-325
	Ellsworth-Antrim	Shale, limestone	100-950
DEVONIAN	Traverse	Limestone, Shale	100-800
	Bell	Shale, limestone	0-80
	Roger City-Dundee	Limestone	0-475
	Detroit River	Dolomite, limestone, salt, anhydrite	150-1400
	Sylvania	Sandstone, Sandy Dolomite	0-550
	Bois Blanc	Dolomite, Cherty Dolomite	0-1000
SILURIAN	Bass Island	Dolomite	50-570
	Salina	Salt, Dolomite, shale, anhydrite	50-4000
	Niagaran	Dolomite, limestone, shale	75-600
	Cataract	Shale, Dolomite	50-200
ORDOVICIAN	Cincinnatian	Shale, Limestone	250-800
	Trenton-Black River	Limestone, Dolomite	200-1000
	St. Peter	Sandstone	0-150
OZARKIAN OR CANADIAN	Prairie Du Chien	Dolomite, shale	0-410
	Hermansville	Dolomite, Sandy Dolomite, sandstone	15-500
CAMBRIAN	Lake Superior	Sandstone	200-2000

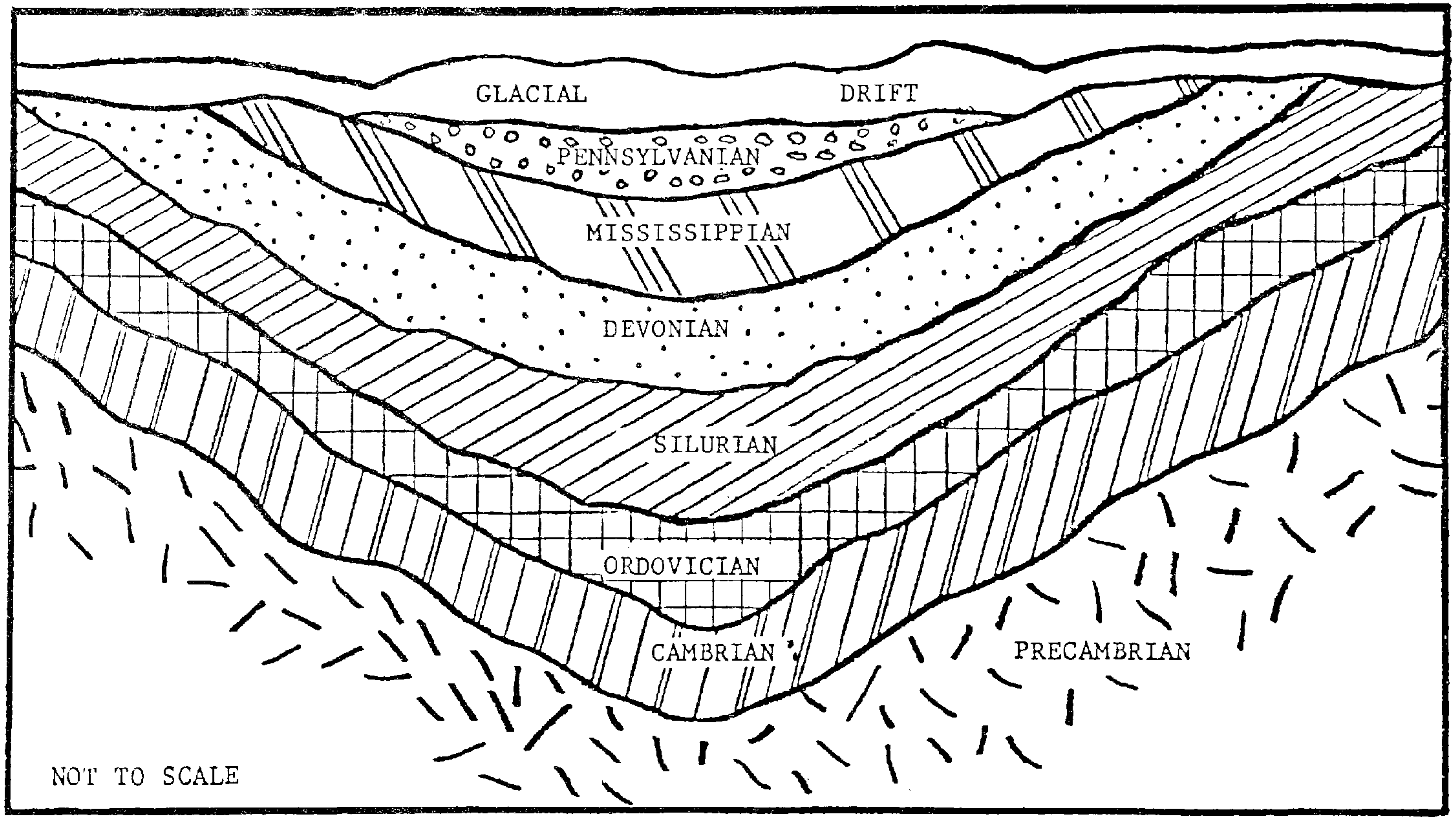

Figure 2. General cross section of the Michigan basin.

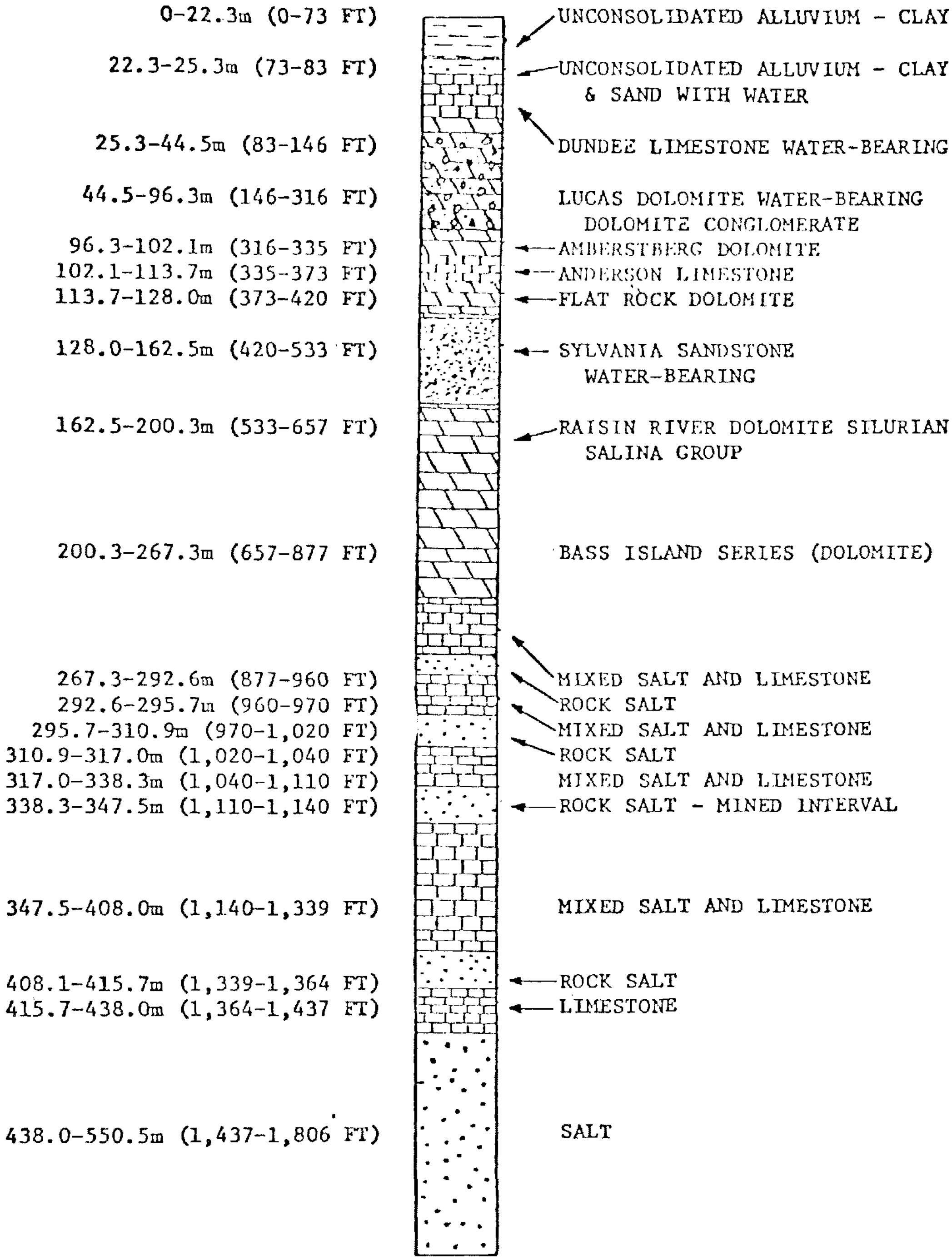

Figure 3. Stratigraphic column of the shaft area.

Below 650 feet, water is generally not encountered and presents no problems. Some water had been encountered during mining, coming from the contact between the salt bed and the overlying unit. The occurrences, however, appeared to be local concentrations and dissipated with time.

Although permeable water-bearing strata exist above and below the mine level, impermeable shale and salt beds form effective hydraulic barriers. Migration of water is not a problem in the mine area.

Sociological --

The selected mine is conveniently located near a major metropolitan area with a heavy industrial output. Above and adjacent to the mine is a mixture of a blue collar residential area and light and heavy industry. Direct access to the mine is provided by several railroads and interstate highways. In addition, the site is a short distance from a large airport.

Specific Description of Selected Mine

Mine History --

Mining of the selected mine began over 50 years ago in a bed of salt at a depth of approximately 1,400 feet. The seam thickness ranges from 25 to 30 feet. A layer of salt is left on both the floor and the roof of the seam to seal it. The thickness actually mined varied from 18 to 27 feet over the life of the mine. During this mining activity, an extensive set of monitoring devices has been installed in the mine. These include convergence gauges and dilation pins. The ongoing monitoring program has established that the mine is stable, and there have been no significant changes in the mine environment since the initiation of mining. Two shafts provide access to the mine. The production shaft is a 16 foot diameter, concrete-lined shaft divided into four compartments, two hoisting compartments and two service compartments. The second shaft, a man and service shaft, is a 4- by 8-foot rectangular, concrete-lined shaft, divided into two compartments.

Mine Layout and Current Activity --

The mining method is conventional room and pillar. Rooms of 60 feet wide with a ceiling height of from 18 to 27 feet are mined at the end of a long gallery, up to several thousand feet long. At regular intervals along the gallery are huge pillars of rock salt 60 by 80 feet, which are the sole means of supporting the roof. Using this system, about 65 percent of the salt is extracted. Several feet of salt are left to preserve the roof and several inches to preserve the floor.

The first step in mining is undercutting. A self-propelled universal undercutter carves a slot six inches high and ten feet deep at the base of the deposit and across the entire room. This kerf provides an expansion area for blasting, thus reducing the amount of explosives required and the amount of salt pulverization. It also makes a smooth mine floor.

A large self-propelled four-boom drill produces 11 to 13 foot deep holes into the salt face in preparation for blasting. Each hole is primed with one-half stick of dynamite, and then the holes are filled with prilled ammonium nitrate. Blasting of the rooms occurs after the shift is over. Each blast brings down 800 to 900 tons of salt.

Before loading out of the salt, a scaling operation removes potentially dangerous pieces of rock salt from the roof and sidewalls. Front end loaders and shovels load the salt on to large bottom-dumping tractor-trailers for haulage to the primary crusher. The haulway and pillars in a similar mine are shown in Figure 4.

From the primary crusher, the salt travels over several thousand feet of conveyor belt to the underground preparation plant. At the preparation plant, the salt is crushed to yield the required product line. Some salt is placed in temporary storage underground (up to 200,000 tons) until needed. Waste salt is stored underground in mined out areas.

The general mine layout is shown in Figure 5, with mining currently taking place in one area. Figure 6 illustrates the typical room and pillar arrangement. Conditions are a comfortable 58°F year round with a relative humidity of 55-56 percent.

Mine Reserve and Future Activity --

Specific information as to reserves is confidential and was not obtained. The entire area surrounding the mine contains mineable salt and could be mined under the proper economic conditions. Exploration has also indicated the existence of mineable seams below the current level. Future plans would involve mining all reserves at the present level before developing lower levels.

Mine Facilities --

Surface -- The mine plant site contains all those facilities essential for the operation of the mine. This includes the offices, warehouses, shops, and salt processing plant. In addition, there are complete truck and rail loading and unloading facilities.

Underground -- The mine itself contains very little in the way of permanent facilities. The area adjacent to the man shaft has been developed to serve as a shelter in case of a mine fire. This was accomplished by erecting fire doors that can be closed in an emergency, sealing this area off from the rest of the mine. The other stoppings in the area are made of salt and should last the life of the mine. Other facilities in the mine include an office, a machine shop, water tanks, and the pump facilities. All other mine facilities are of a temporary nature and are frequently relocated as the production areas change.

Shafts and Hoisting -- The existing production shaft is concrete-lined with an interior diameter of 16 feet. As shown in Figure 7, this shaft is divided into four compartments, two for hoisting and two service compartments. Balanced hoisting is achieved using one electric hoist.

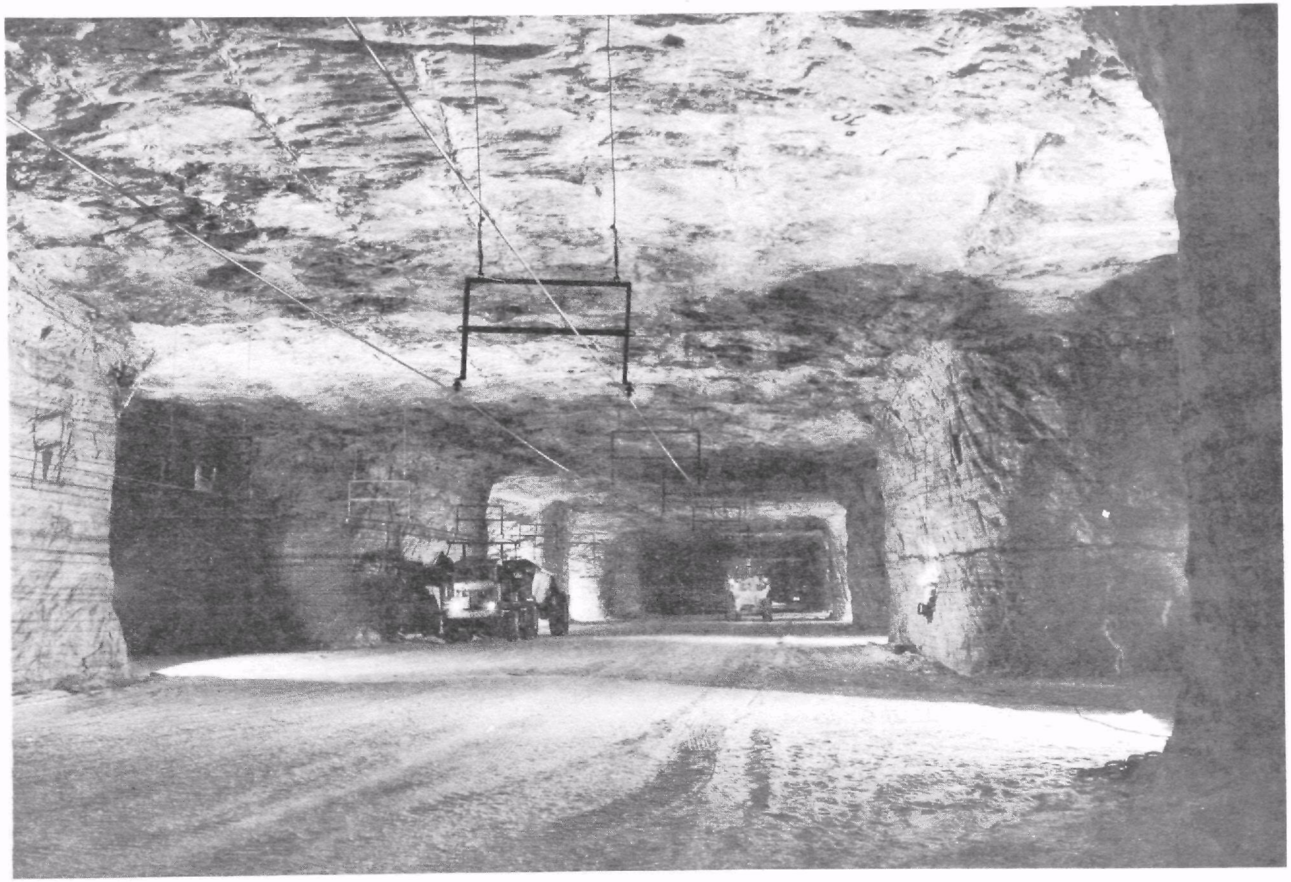

Figure 4. Photo of the main haulway in a salt mine (courtesy of International Salt Company).

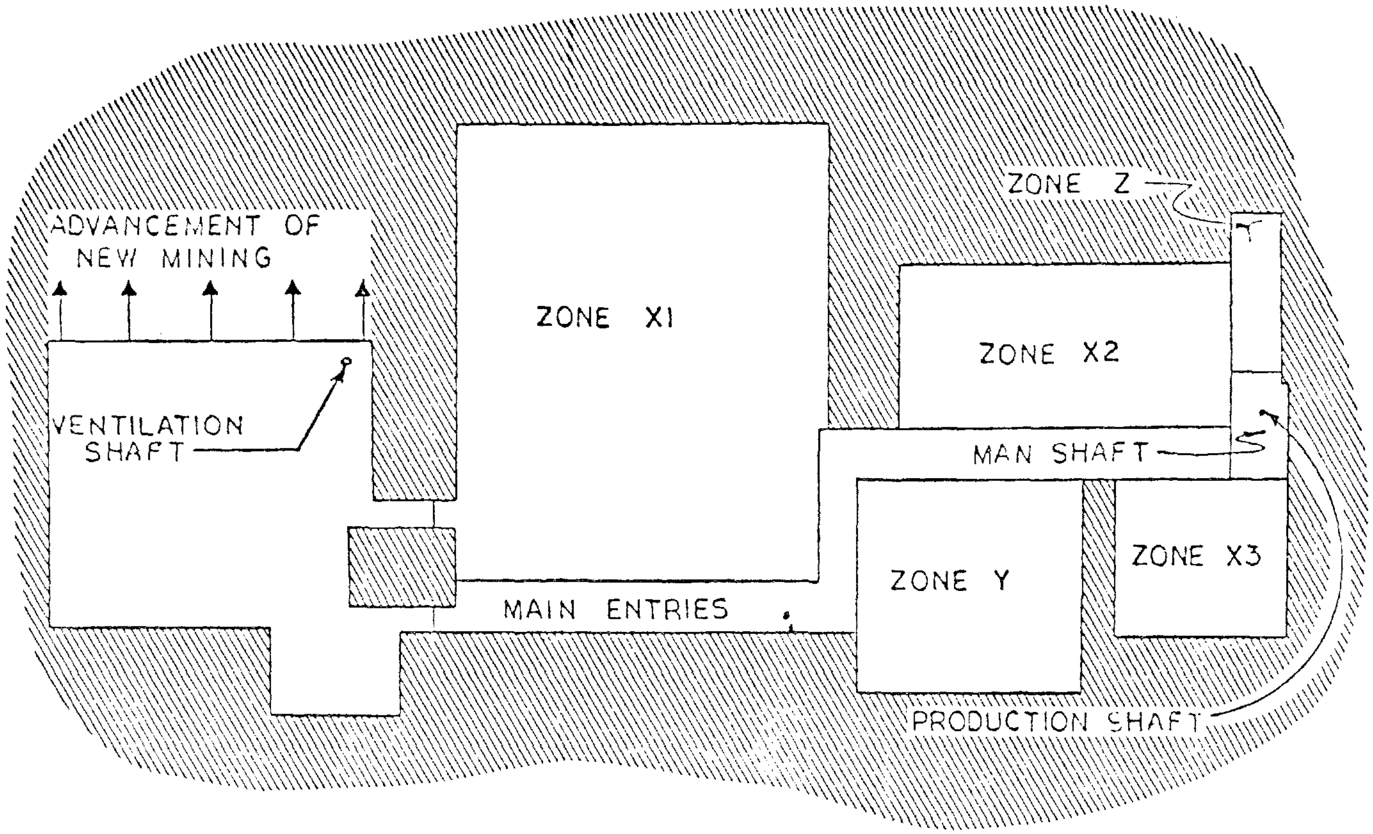

Figure 5. General mine layout.

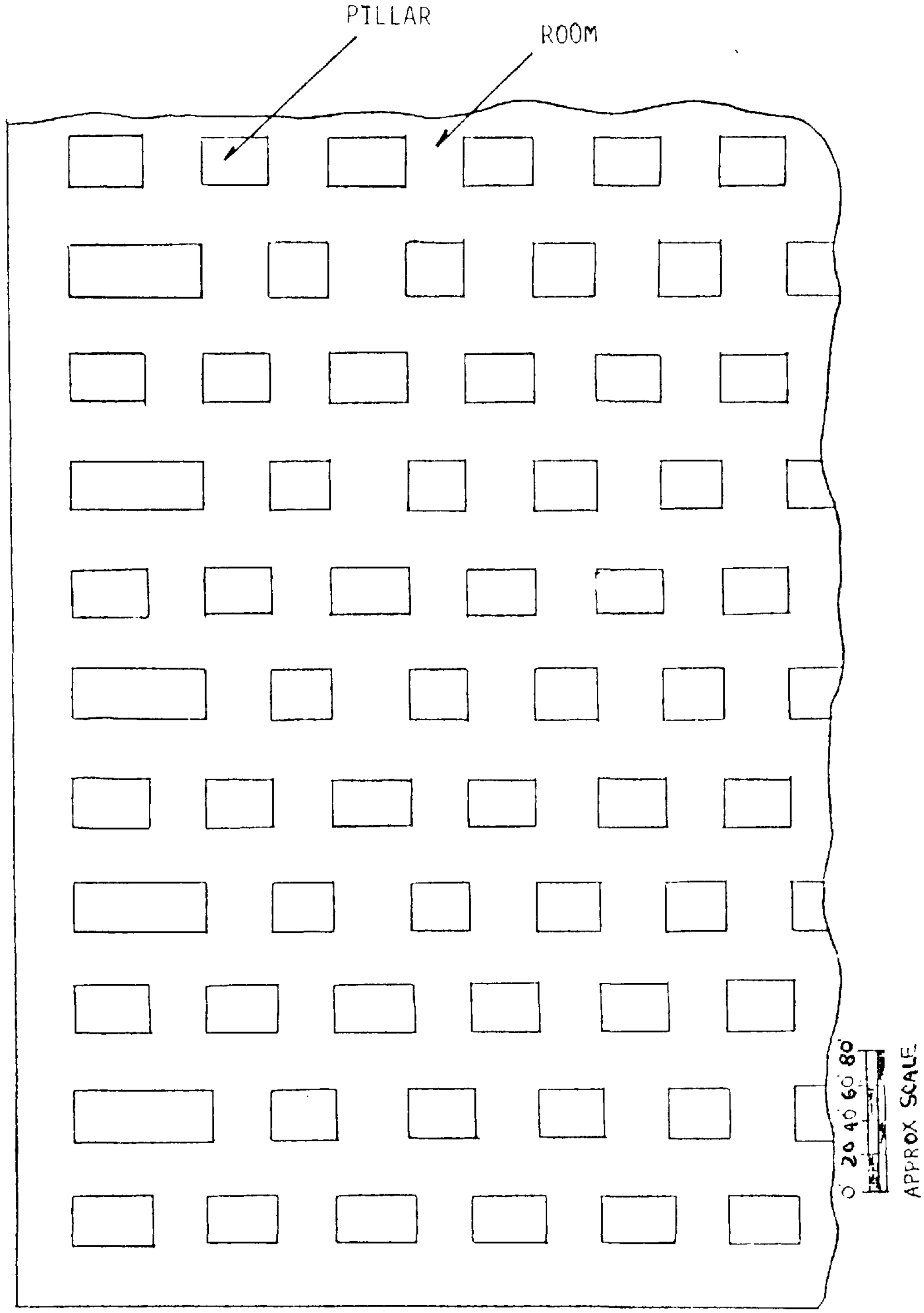

Figure 6. Typical room and pillar arrangement.

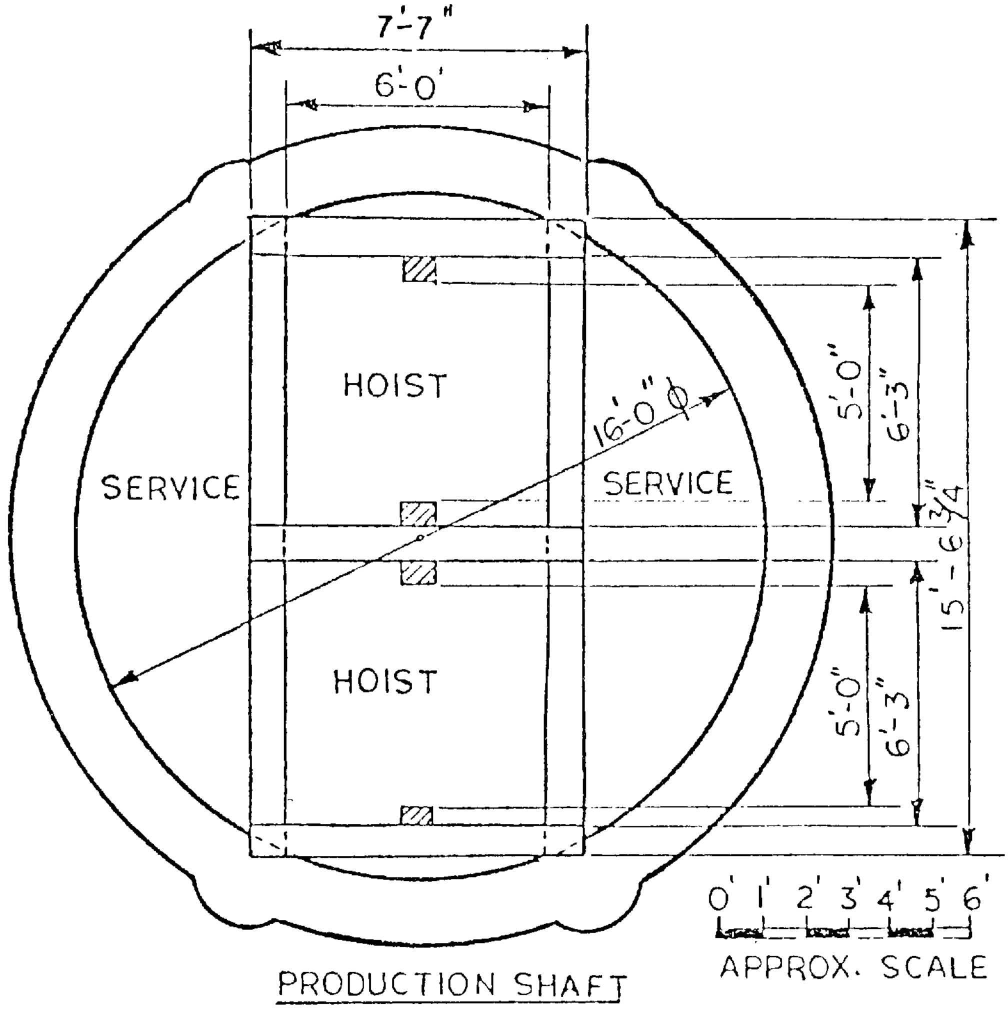

Figure 7. Cross section of production shaft.

Production hoisting takes place in two skips, each with a 10-ton capacity. Additionally, this shaft can be used for hoisting men, utilizing compartments above the skips.

The concrete-lined man shaft is 4 by 8 feet in cross section. This two-compartment shaft utilizes a balanced electric hoisting system. Each compartment contains a double deck man-cage, capable of holding three men per deck.

Drainage -- The small quantity of water in the mine comes from one of three sources: (1) the formations penetrated by the shafts, (2) condensation from the ventilation air, and (3) connate water. Connate water may occasionally be found at the contact between the top of the salt and the overlying bed. Such occurrences are, however, unusual, yielding only small flows that cease shortly after mining. No special drainage facilities are used, and the water produced is absorbed by waste salt in the area.

Drainage facilities are located in the shaft area. Water rings, emplaced around the shaft, pipe formation water to the mine level for removal to the surface. Additional water is condensed from the ventilating air as it reaches the mine and collected in storage tanks for removal to the surface.

Water is collected underground in several small sumps and pumped to one of two underground holding tanks. Combined storage capacity is approximately 50,000 gallons. Pumps take the water to the surface in a single lift.

Ventilation -- In the present ventilation system, intake air (160,000 cfm) is drawn down through the two service compartments of the production shaft by a fan located in the mine.

Fresh air passes to the working areas through an intake airway that is isolated from the rest of the mine by a brattice line. In the working area, the brattice consists of temporarily hung brattice cloth. The remainder of the brattice line is of a permanent nature consisting of either salt block construction or fine salt piles capped with a brattice cloth-foam seal. Older brattice lines were made of salt blocks cemented together by fine salt. Typically, these are six feet wide at the base, tapering to several feet at the roof. Newer brattice lines have been formed by piling waste salt in the cross-cuts to within several feet of the roof. At the roof line, brattice cloth is hung and sealed by spraying with a polyurethane foam.

The return air leaves the working area and follows the abandoned workings to the shaft area. Air reaches the surface via the hoisting compartments of the production shaft and through the man shaft. In addition to the main fan, auxiliary fans are used in the mine, as needed, to provide circulation in the working areas.

Electrical System -- Power (4,800 volts) is supplied to the mine by two separate underground lines. Only one is used at any given time, with automatic switching in case of line failure. Should both lines fail, emergency mobile generators can be brought to operate the fan and hoist systems.

The underground electrical distribution is by necessity a flexible one, adapting to the needs of production. All cables, up to the production area, are roof mounted. A 250-volt DC, 75 kilowatt motor-generator set is available underground.

Miscellaneous Underground Facilities --

Non-potable Water -- Non-potable water is piped underground, under natural head. The water line extends down the production shaft service compartments and out approximately 3,000 feet away from the shaft.

Diesel Fuel -- Diesel fuel is piped underground, under natural head. The fuel line extends down the production shaft service compartment and approximately 3,000 feet away from the shaft. A 500-gallon storage tank is available.

Structural Condition --

The structural integrity of the mine has been preserved after more than a half century of operation. Areas mined 50 years ago appear to have undergone no degradation or failure and are as competent as the areas currently mined. Stability has been confirmed by monitoring with convergence gauges and dilation pins. No faults, fractures, or other anomalies are known to exist.

Available Storage Space --

An upper limit on the storage space in the mine has been estimated from production figures and mine maps. This, however, reflects the void left by mining and must be reduced to reflect actual conditions in the mine. Some areas may not be usable as storage sites because of:

- Structural weakness in the roof and pillars may prohibit use of some areas as storage space.
- A certain amount of space will be unavailable because of the needs of the storage operation itself. This will include space for items such as ventilation, haulage and escape ways, offices, and unloading areas.
- If the storage operation is to be contemporaneous with salt mining operations, some space will be required for ventilation, haulage, underground preparation, and salt storage. Ultimately, this space could become available for waste storage.
- Waste salt produced in the course of mining and processing is often returned to the mine for storage in mined out areas.

The total open space in the mine designated for the waste storage is estimated to be 500,000,000 cubic feet. This is located in the following areas as designated in Figure 5.

Area	Cubic Feet
X_1	210,000,000
X_2	70,000,000
X_3	40,000,000
Y	70,000,000
Z	10,000,000
Haulways and service areas	100,000,000
Total	500,000,000

Additional space is available in the area of current mining and is being created at the approximate rate of 15,000,000 cubic feet per year. Although this space is not designated for waste storage, the potential exists for its long-term utilization.

Section 4

STORAGE FACILITY DESIGN AND OPERATION

A detailed description of the hazardous waste storage facility is presented in this section. The description is based on Case 1, the base case, which has received the most detailed design effort. The facilities of other cases (Cases 2 through 5) will be discussed in the latter part of this section. Material flow charts, process flow diagrams, and plant layout presented in this section are all for the base case. General design and operational criteria of the overall plant facility are presented, followed by description of surface facilities, subsurface facilities, and alternative cases.

GENERAL DESIGN AND OPERATIONAL CRITERIA

The plant facilities are designed to receive, store, treat, containerize, transfer to staging area, transfer to hoisting area, lower into mine, transfer to storage cell area, and store the four types of hazardous wastes. The plant operational logic is shown in Figures 8 through 12. Figures 8, 9, and 10 show the flow of Type A, B, C, and D wastes through sequential steps from receiving at the plant gate to placement in the storage cells. Figure 11 shows the flow of chemicals and containers used in the plant. Figure 12 shows the material flow in the effluent treatment process.

As pointed out previously, no operating underground hazardous waste storage plant presently exists at which the waste is treated and recontainerized before the underground emplacement. Design criteria based on actual operating experiences are not available. The scope of this study allows only the formulation of a reasonable design criteria, which will allow the conceptual design of the storage facilities.

A number of general criteria were formulated to arrive at a reasonable concept of the surface and subsurface facilities and a reasonable assessment of their costs. The parameters involved are:

- Plant operating hours
- Modes of waste transport
- Types of waste shipping containers
- Waste surface storage
- Waste treatment methods and capacities
- Waste containerization methods and types of containers
- Effluent wastewater treatment and disposal method
- Modes of containerized waste transport into mine and storage areas
- Storage methods

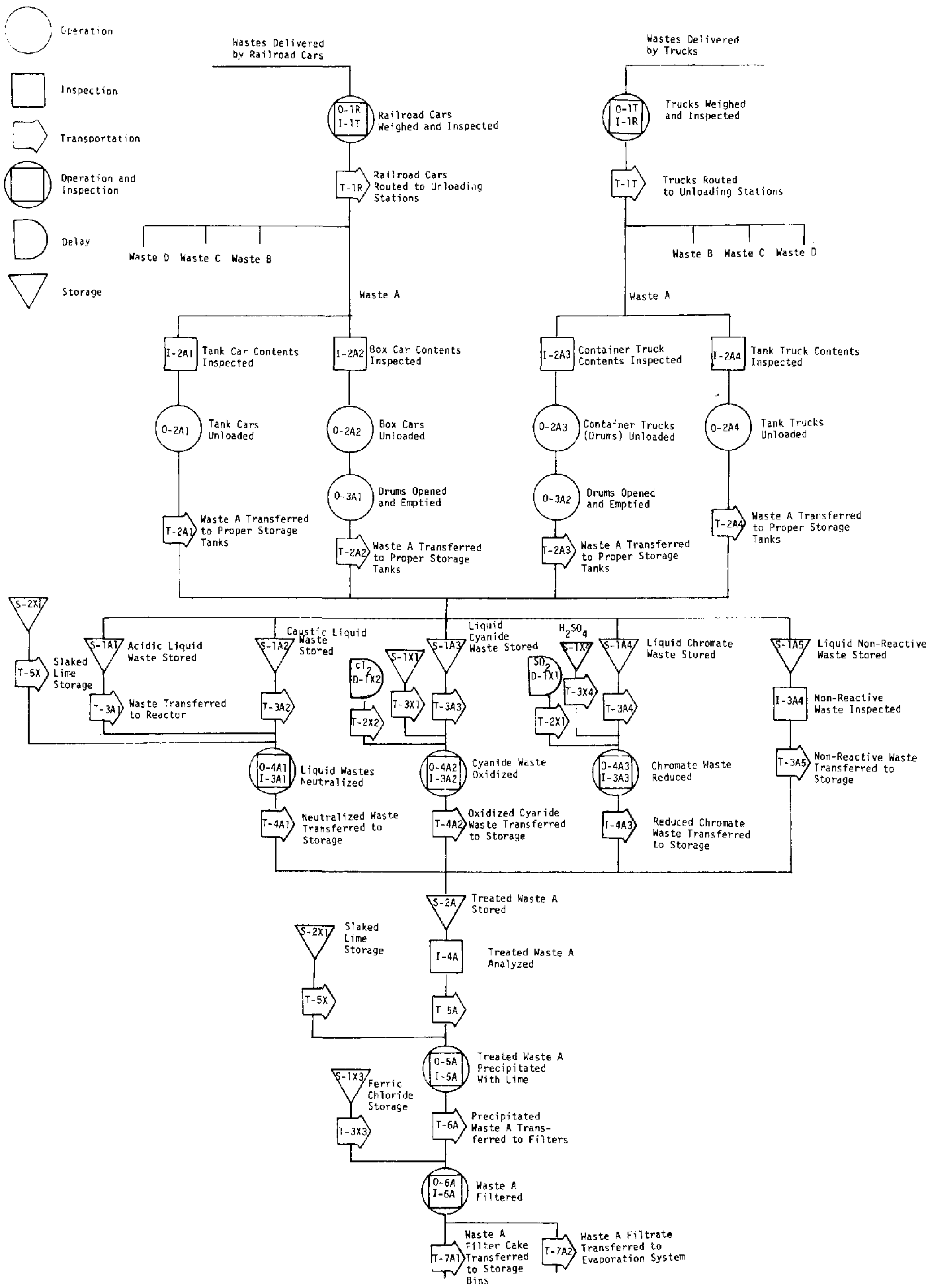

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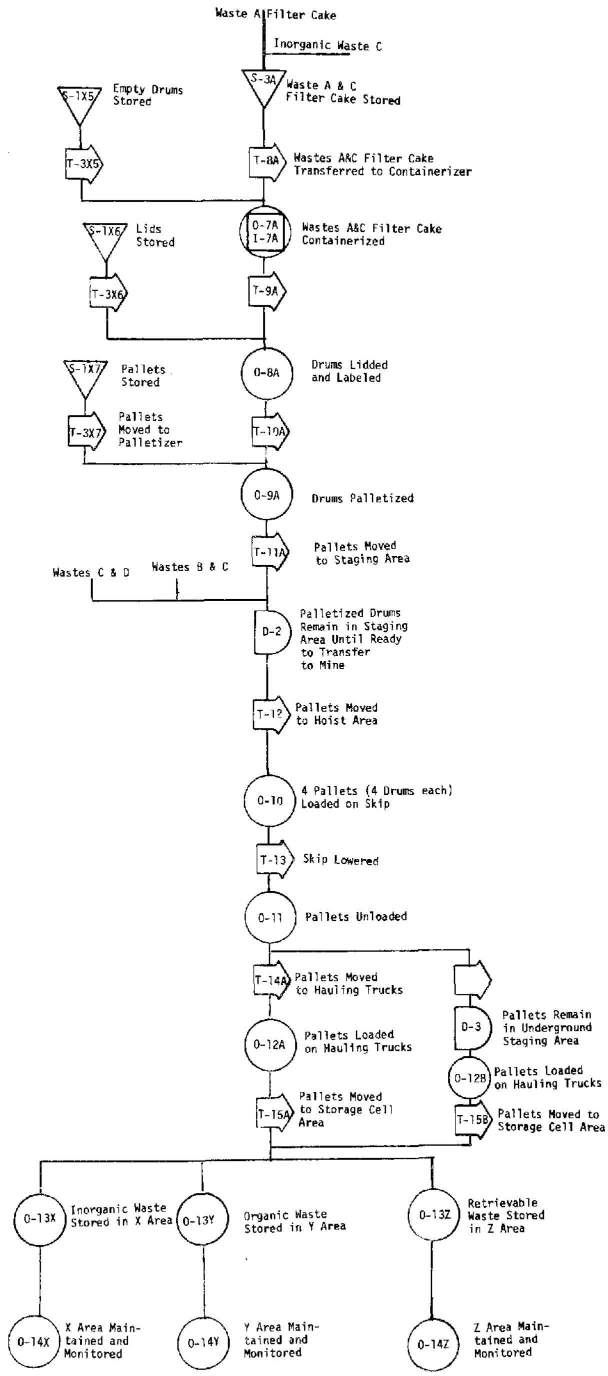
Figure 8. Material flow chart -- Type A wastes.

Figure 8 (continued)



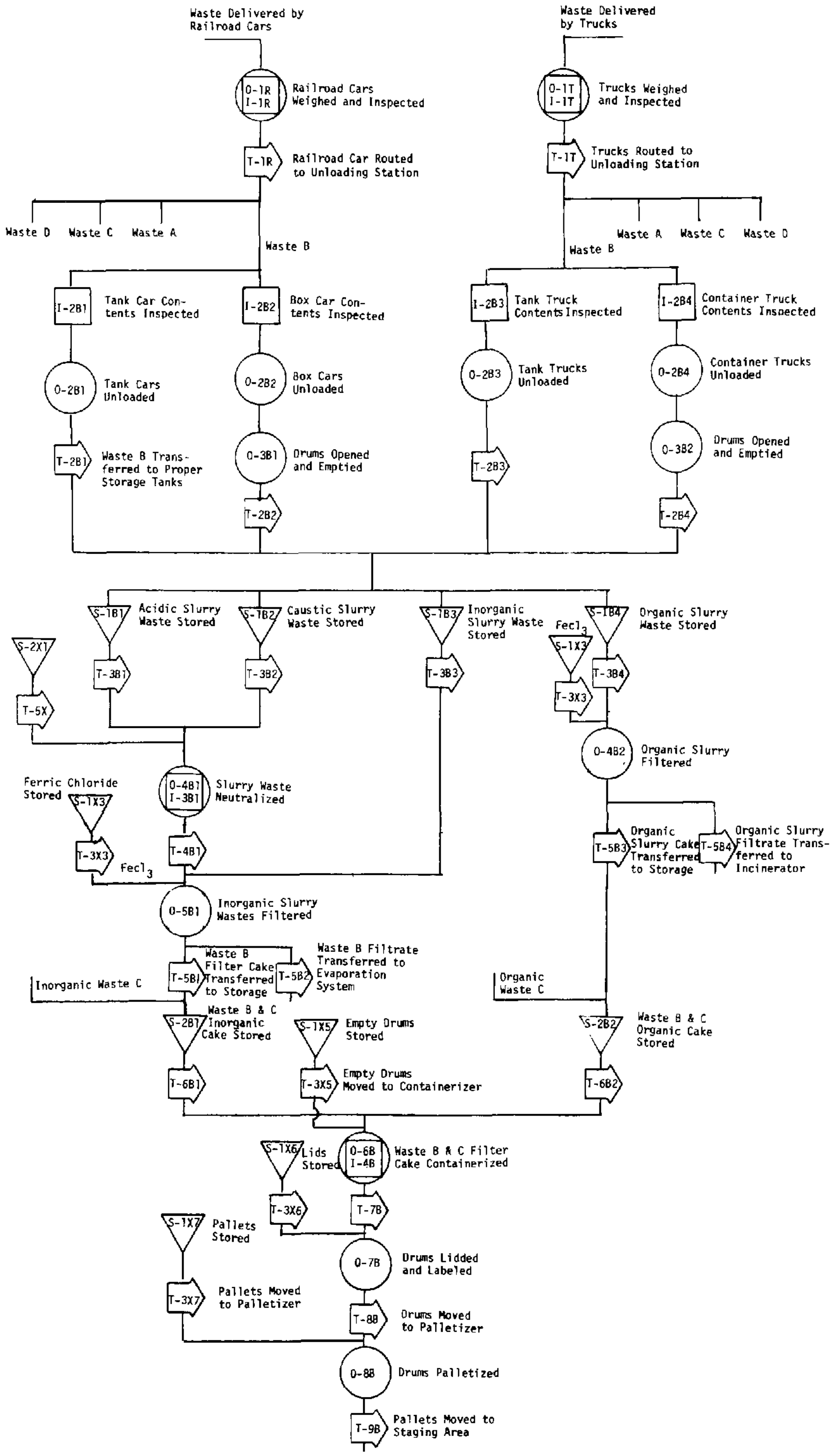


Figure 9. Material flow chart -- Type B wastes.

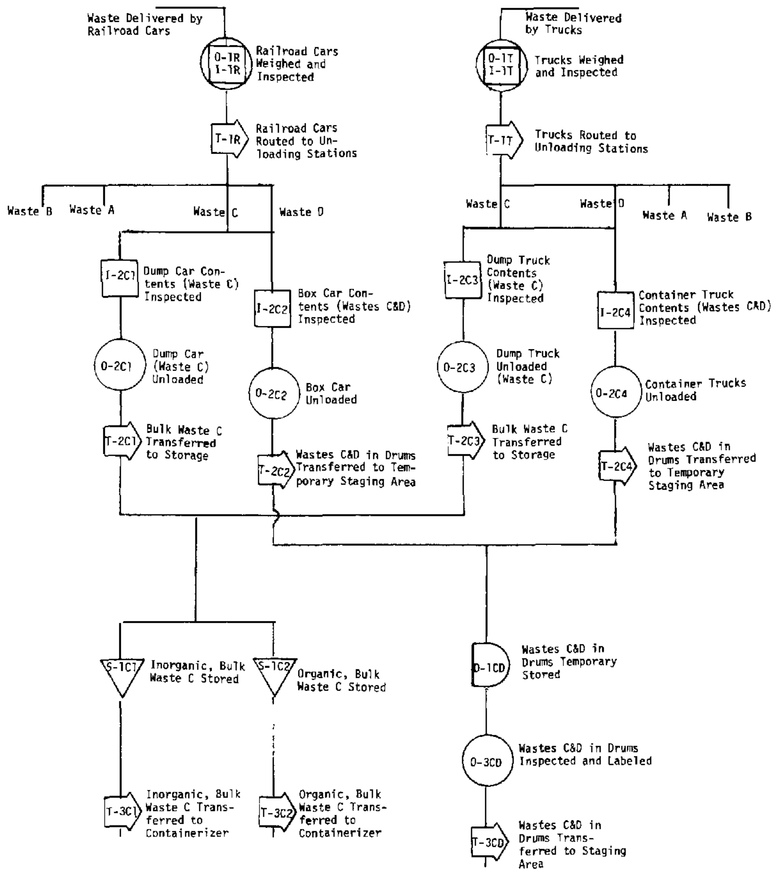


Figure 10. Material flow chart -- Types C and D wastes.

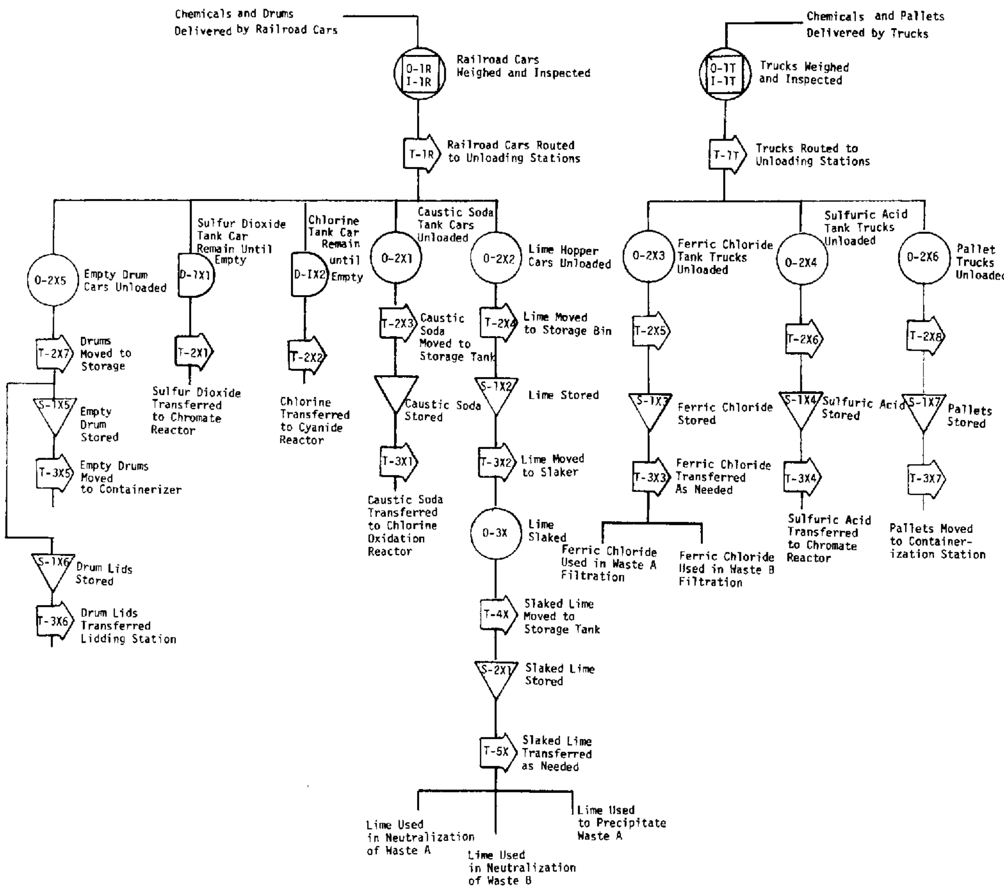


Figure 11. Material flow chart -- chemicals and containers.

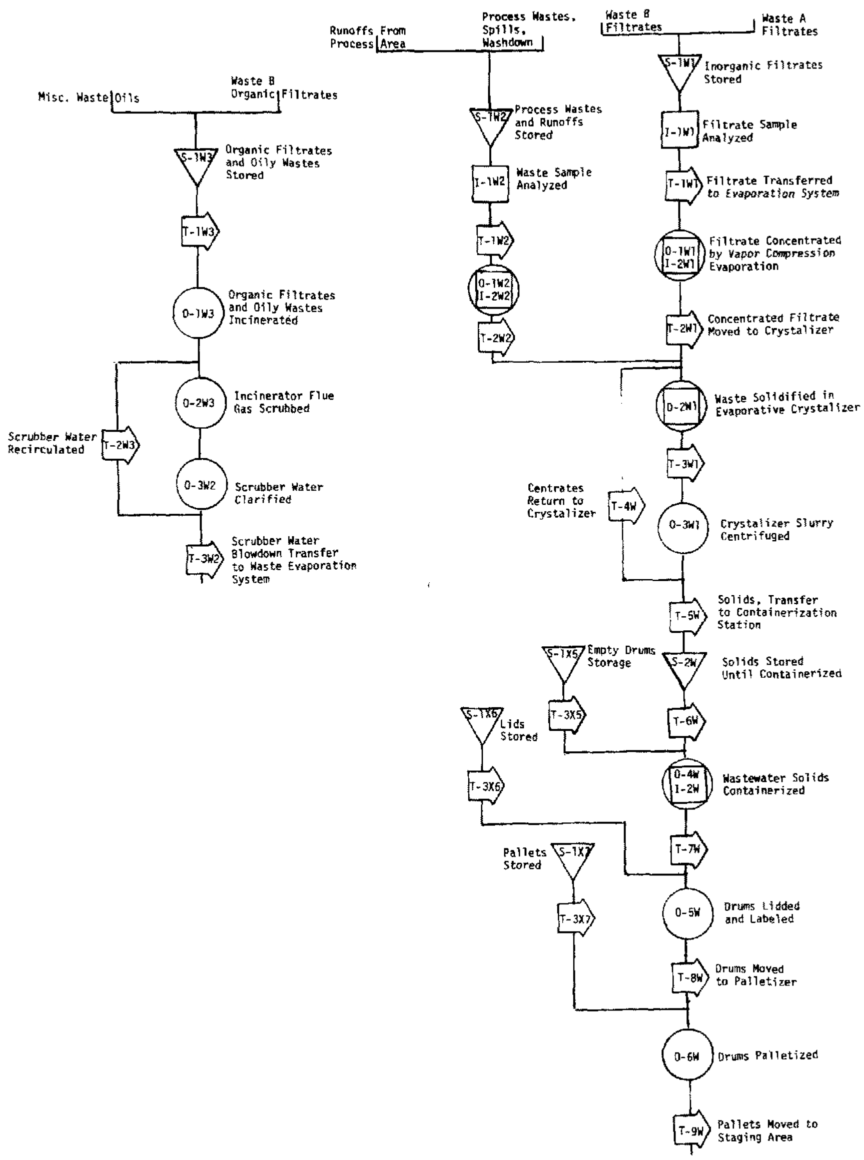


Figure 12. Material flow chart -- plant effluent treatment.

Plant Operating Hours

Both surface and subsurface facilities will be operated primarily on the basis of two production shifts and one maintenance shift per day, six days per week. Some activities that deviate from this basis are discussed in appropriate places.

Modes of Waste Transport to Storage Plant

All wastes will be transported from the waste generators to the site by rail and truck. The plant will receive at least 24 hours advance notice of each proposed shipment, including all particulars on the waste characteristics. The plant may place a "hold" on the shipment. Railcar loads will be a nominal 50 tons net; truck loads will be a nominal 20 tons net.

Types of Shipping Containers

Rail shipments will be by tank car (bulk liquids and slurries), by sealed bottom-dump hopper cars (bulk solids), and by box cars (drummed liquid, slurries, solids). Truck shipments will be by tank truck (bulk liquids and slurries), by sealed end-dump truck (solids), and by container truck (drummed liquids, slurries, solids). Type A and B drummed wastes to be opened may be in any suitable 55-gallon steel drum. Type C and D drummed wastes must be in the same type of 55-gallon drum that will be used to containerize the treated waste.

Waste Surface Storage

All bulk wastes will be stored in closed tanks or bins. Drums will be stored in a warehouse-type storage building. No open storage will be permitted. Unloading and storage areas will be paved and diked to impound spilled materials. Surface runoff from potential contaminants will be collected and treated. Liquid and slurry waste surface storage capacity will be a nominal four days at 100 percent operating capacity. Solid waste storage will be a nominal six days at 100 percent operating capacity. Enough tankage and bins will be provided so that filling, analyzing, and emptying operations can be accommodated without difficulty. Eight days of surface storage capacity will be provided for drummed waste; stored drummed waste can be worked off when production in waste treatment and containerization is below capacity.

Waste Treatment Methods

Waste treatment operations will be designed to convert wastes to a form suitable for safe, convenient handling and emplacement in the mine. Soluble or reactive hazardous materials will be converted to stable forms. Free water and free organics or oily material will be separated from the wastes. Each waste type (and subtype) will be processed at design throughput each day:

- Type A Wastes: Hexavalent chromium will be reduced to trivalent chromium then precipitated as $Cr(OH)_3$. Cyanide will be oxidized to nitrogen and CO_2. Acid and alkaline wastes will be neutralized. Heavy metals will be precipitated as hydroxides. Precipitates will be dewatered to a minimum 40 percent solids cake for containerization.

- Type B Wastes: Acid and alkaline wastes will be neutralized. Inorganic and organic wastes will be handled separately. All wastes will be dewatered or deoiled to a minimum 40 percent solids cake for containerization.

- Type C Wastes: Solid wastes will receive no treatment.

- Type D Wastes: Wastes designated for retrieval will receive no treatment.

Waste Containers and Containerization Methods

In this study only one type of container was considered, a 16 gauge, 55-gallon open top steel drum with a lever-ring closure. Containerization will be automated as far as is practicable with multiple drum filling lines. Organic and inorganic wastes will be containerized separately. Exposure of workers to the wastes will be minimized.

Effluent Waste Treatment Methods

Aqueous filtrates, process wastewater, and contaminated surface runoff will be evaporated to recover water as a condensate and solids, including hazardous components, as a filter cake. Recovered condensate water will be reused as much as possible. Recovered solids will be containerized and placed in the mine. Organic filtrate will be incinerated.

It is obvious that there are alternatives to these general criteria adopted for the surface facilities. And it is recognized that alternative methods of operation could significantly affect the cost of waste emplacement. However, these criteria allow the design and specification of reasonable surface facilities at a level of detail needed for cost estimation.

Modes of Waste Transport into Mine and to Storage Area

The transport of waste into the mine includes removing the drummed waste (four drums on each pallet) from the surface staging area to the hoist loading area, lowering four pallets (16 drums) on each hoisting cycle into the mine, and then transporting these pallets to the storage area using flat-bed haul trucks. Underground staging will be used if the transport to the underground storage area has to be stopped.

Storage Method

Three storage areas will be used: Zone X (Figure 5) for inorganic wastes, Zone Y for organic wastes, and Zone Z for the wastes to be stored temporarily (Type D wastes). Within each storage zone, waste may be stored in several storage cells simultaneously as needed. Unloading of the pallets from the haul trucks, short distance movement, and final emplacement of these pallets into the storage cell will be done using forklifts. The pallets will be stacked as high as possible in all the storage cells except those in Area Z. The Type D wastes to be stored temporarily in Area Z will be stacked in two-drum layers, so that they can be retrieved readily.

SURFACE FACILITIES

The above ground waste handling process is summarized in Figures 13 and 14. Figure 15 is a plot plan showing the conceptual layout of the surface facilities, which, as designed, will cover about 17 acres of fenced area. The surface facilities will be described with the aid of process flow diagrams, Figures 16 through 25. Description of the surface facilities is divided into the different waste types and their treatment pathways. Unit process design criteria and their specifications used for cost estimation are summarized in Appendices B and C.

Type A Waste Processing

Six hundred tons of Type A wastes will be received daily. Type A wastes include 100 TPD of chromate waste (A-1), 100 TPD of cyanide waste (A-2), 100 TPD each of acid and alkaline wastes (A-3), and 200 TPD of nonreactive waste.

Waste Receiving and Storage --

Type A wastes will be transported to the plant either in bulk form by tank trucks and tank cars or in 55-gallon drums by container truck and box car (Figure 16).

After weigh-in and inspection, tank trucks will be routed to the "A" truck unloading station and connected by a flexible hose to the unloading pump appropriate for Type A wastes. The tank truck contents will be transferred to the appropriate waste storage tank. The pumps and tanks for each waste subtype will be piped separately.

The same procedure will be used in unloading rail tank cars after weigh-in, spotting and inspection.

Drummed waste in trucks will be spotted at the receiving dock and unloaded by forklift trucks. The drums will be moved to the drum open and dump station. Drumheads will be automatically cut off, and the drum contents will be dumped into a tank. The tank will be connected to the appropriate waste subtype transfer pumps and storage tank. Emptied drums (and heads) will be transported to the drum cleaning facility. The transfer tank will be flushed and drained before changing to another waste subtype. Box cars of drums will be spotted at a separate unloading dock, used also for Type B, C, and D drummed waste. The cars will be unloaded by forklift trucks and transported by tractor-trailer cars to the Type A waste drum open and dump station for transfer to the appropriate storage tanks. Storage tank capacities will be 25,000 gallons and 50,000 gallons. Each waste storage tank will be equipped with a side-entering agitator to mix the tank contents. The tank walls and bottom will be lined with a suitable corrosion resistant material. Where

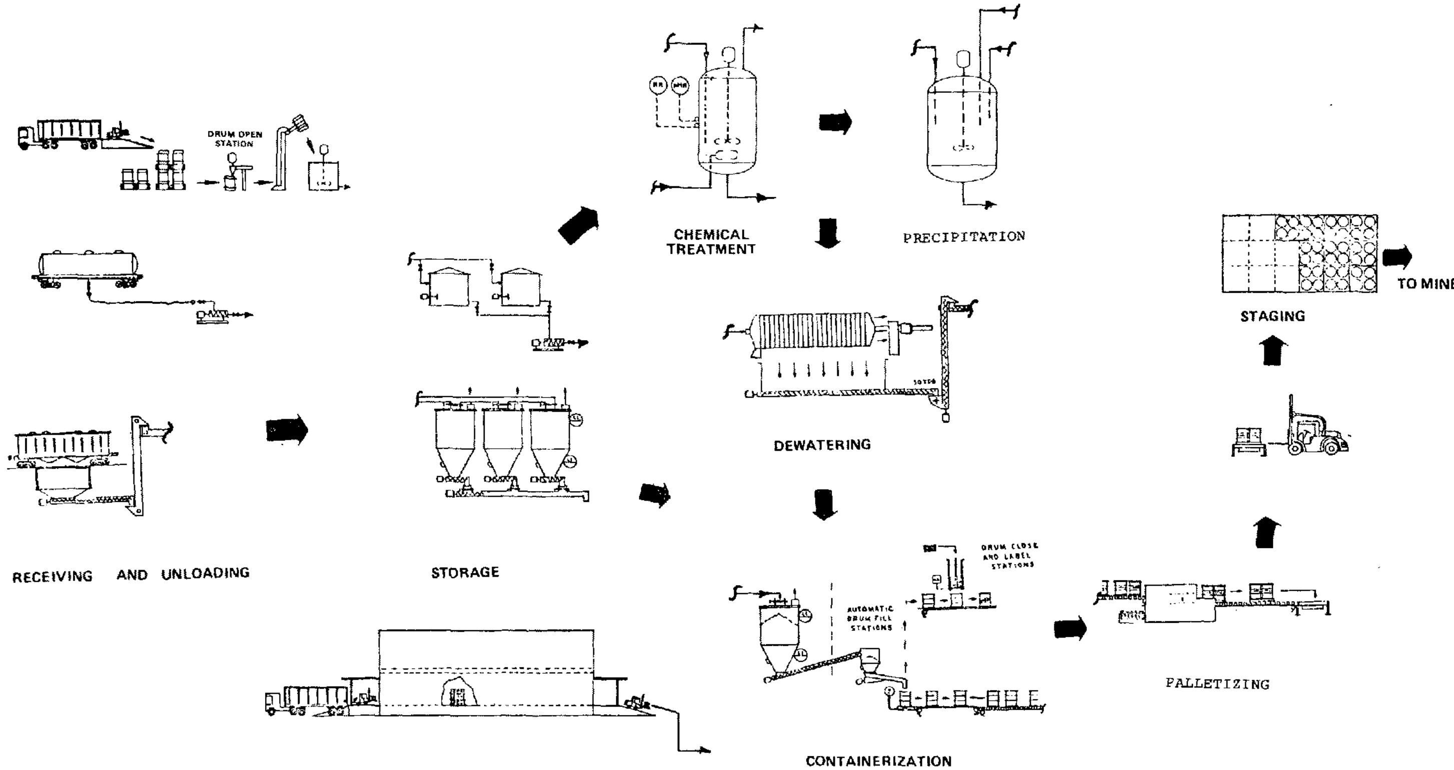


Figure 13. Schematic diagram of surface operation.

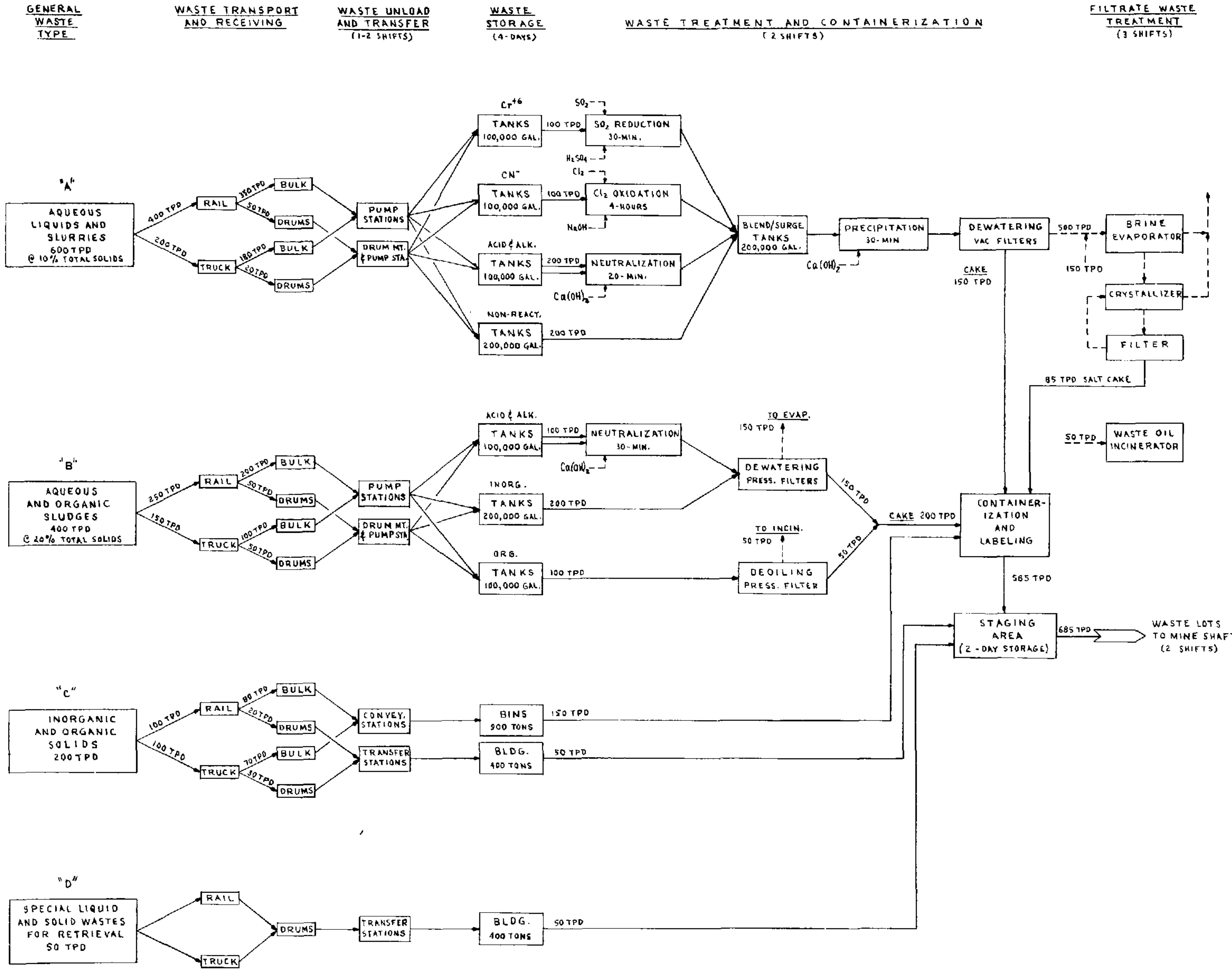


Figure 14. Block flow diagram of surface operation.

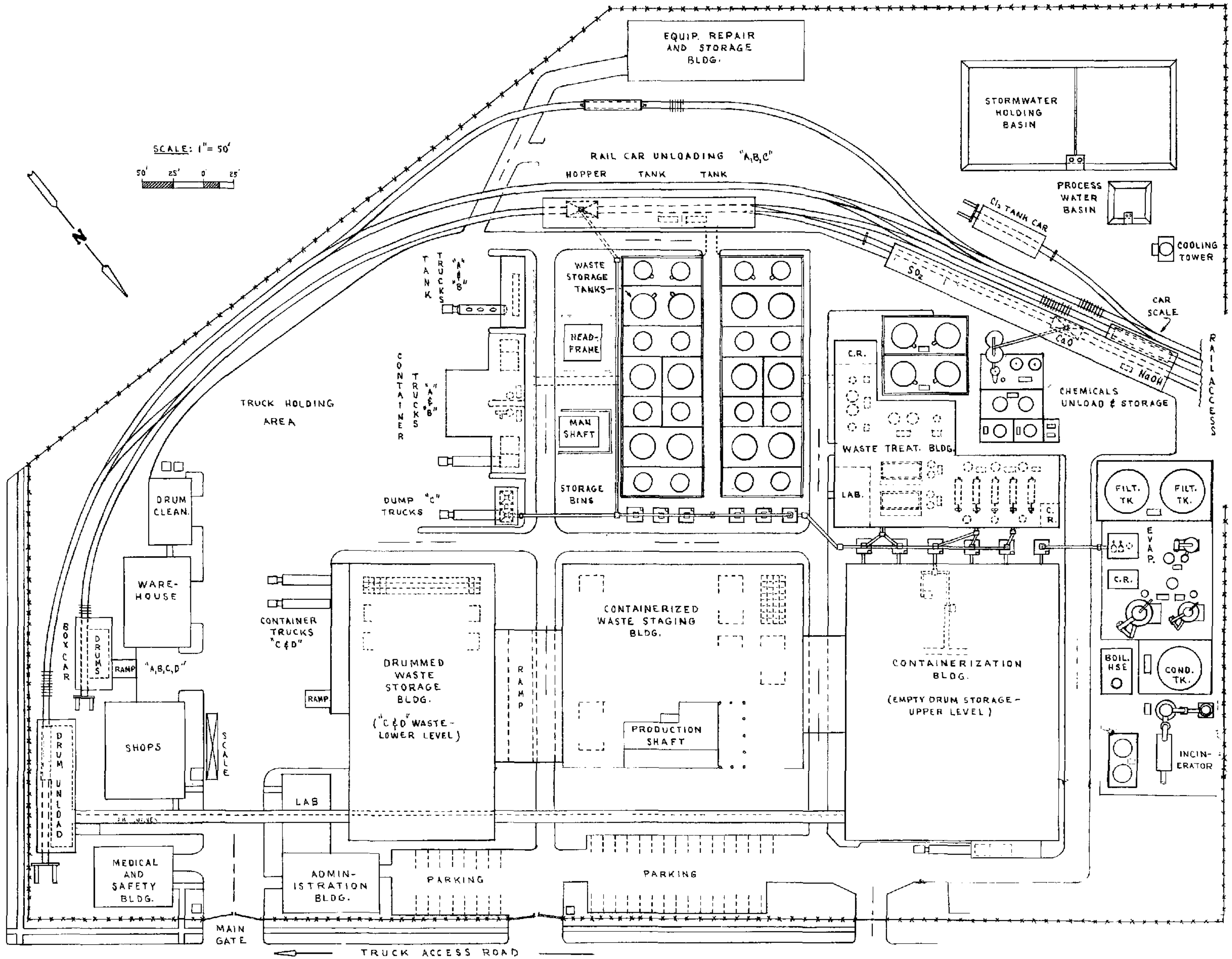


Figure 15. Plot plan of surface facilities.

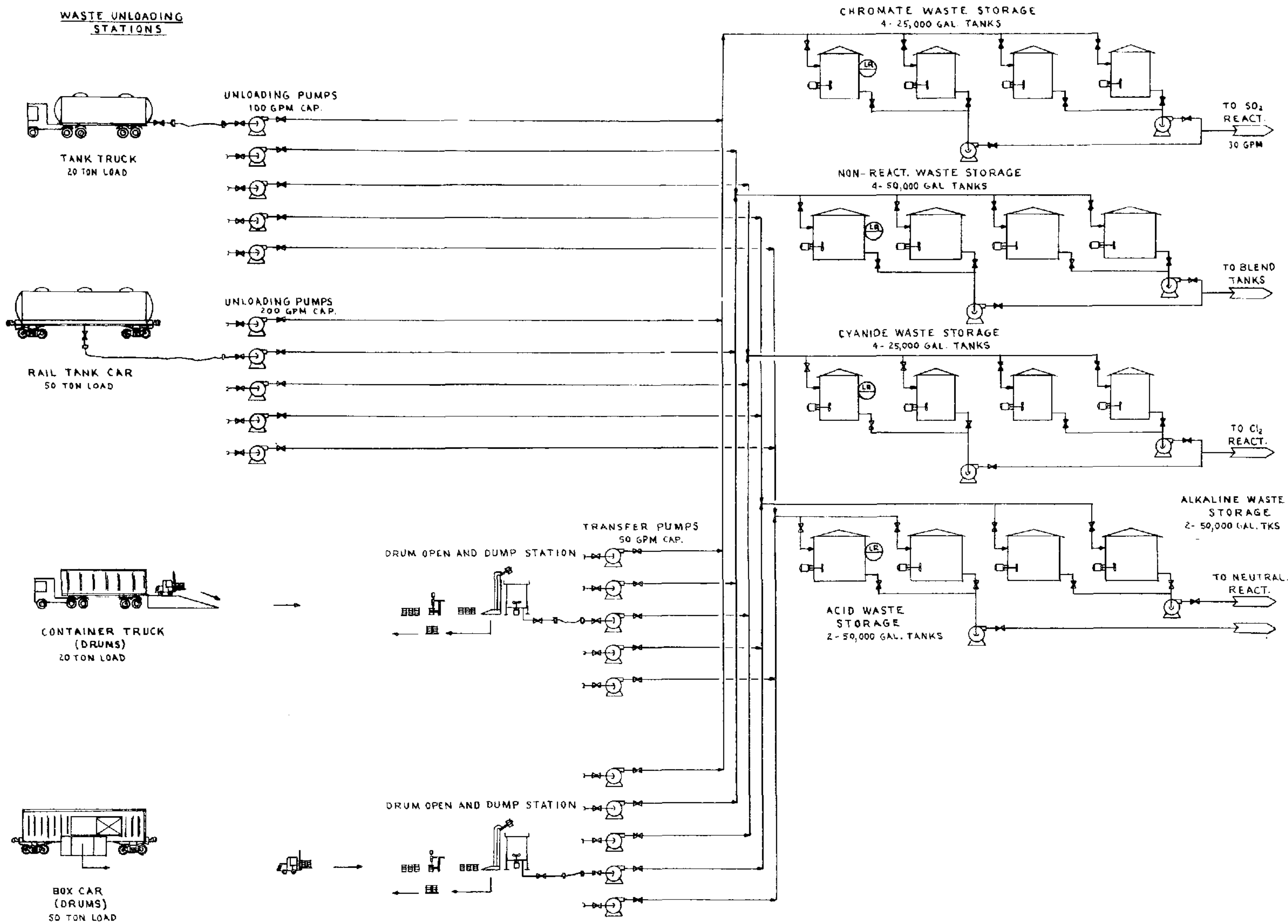


Figure 16. Process flow diagram -- Type A waste unloading and surface storage.

four tanks are provided for a waste subtype, normally one tank will be empty, one tank will be filling, one tank will be full and being analyzed, and the last will be in the appropriate waste treatment system as described below.

Chromate Waste Treatment (Figure 17) --

Chromate waste will be pumped from the storage tank on flow control to a pH adjustment vessel where sulfuric acid (78%) will be added, if necessary, to bring the pH down to 2 to 3. The waste will enter the top of the stirred, baffled reactor (1,000 gallons), where it will be contacted with sulfur dioxide (SO_2) sparged in from the bottom. An oxidation-reduction potential (ORP) controller on the reactor effluent stream will ensure sufficient SO_2 flow to reduce all the hexavalent chromium to the trivalent form. Treated waste will be pumped to a blend/surge storage tank. Vent gas water vapor, containing traces of SO_2, will be piped to the vent collection system. One hundred tons of chromate waste can be processed during two shifts of operation.

Cyanide Waste Treatment (Figure 17) --

Cyanide waste will be pumped from the storage tank and split into two streams on separate flow controls. Each stream will enter the top of a stirred, baffled reactor (3,600 gallons), where it will be contacted with chlorine sparged in from the bottom. An ORP controller will ensure sufficient chlorine flow to oxidize all the cyanide to nitrogen and carbon dioxide (CO_2). Sodium hydroxide (50%) solution will be added to the vessel to maintain alkaline conditions. A pH monitor will be used as an indicator for adjusting the NaOH addition rate. Treated waste will be pumped on level control to a blend/surge tank. Vent gas nitrogen, containing water vapor and traces of Cl_2, will be piped to the vent collection system. Fifty tons of cyanide waste can be processed in each reactor during two shifts of operation. Reaction conditions for the run will be based on prior analysis of the waste in the storage tank.

Acid and Alkaline Waste Treatment (Figure 17) --

Acid and alkaline wastes will be pumped from the storage tanks on flow control to the stirred, baffled neutralization vessel (1,200 gallons). Calcium hydroxide (25% slurry) will be added to the vessel on pH control to neutralize excess acidity. Cooling water will be circulated on temperature control through the vessel jacket to remove heat of neutralization. The neutralized waste will be piped to the vent gas collection system. One hundred tons each of acid and alkaline waste can be processed during two shifts of operation, and conditions for the run will be based on prior analyses of the wastes.

Nonreactive Waste Handling (Figure 17) --

Nonreactive waste will be pumped on flow control to the appropriate blend/surge tank, where it will be mixed with other treated wastes. It can be processed in the downstream waste precipitation section directly, bypassing the blending step.

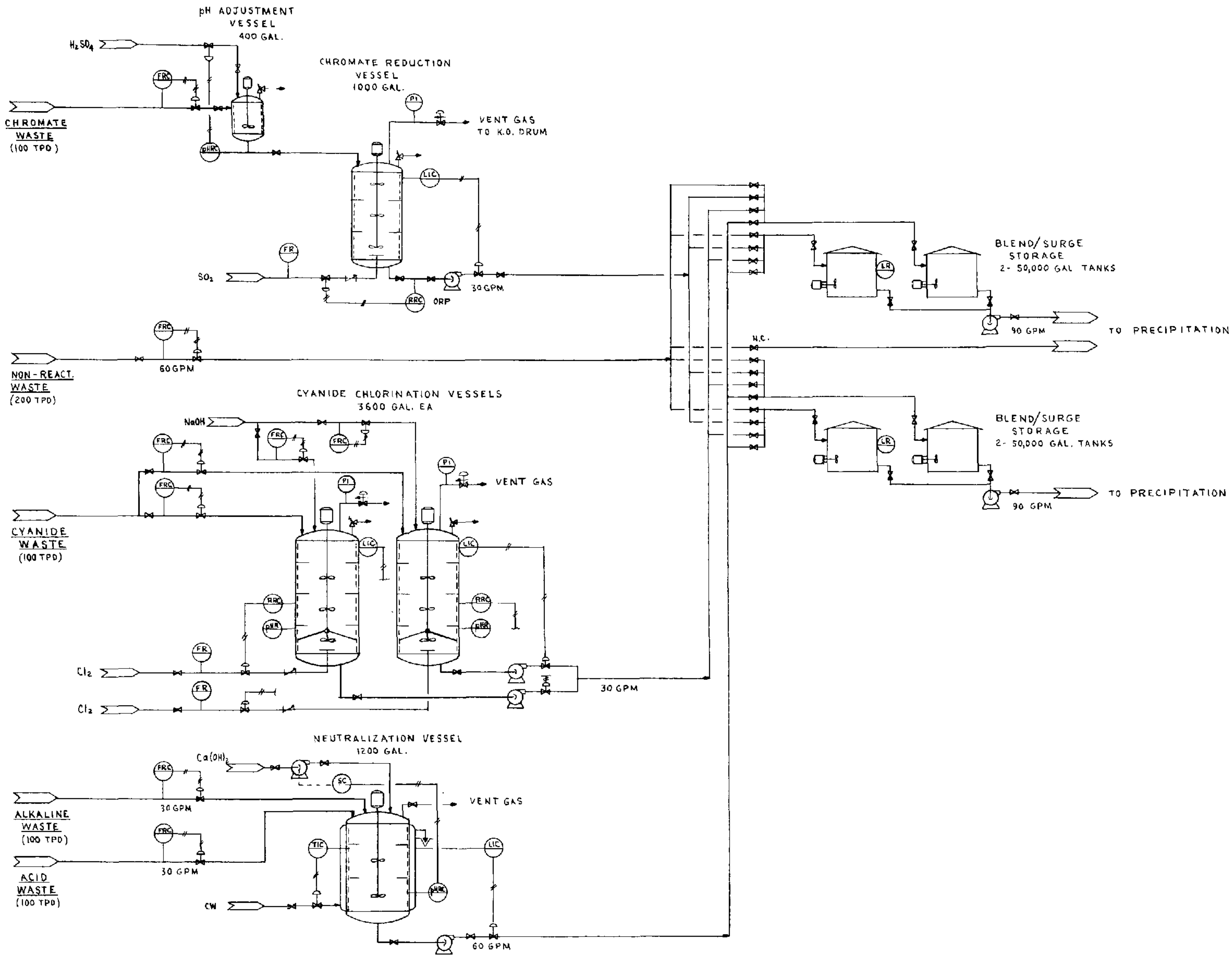


Figure 17. Process flow diagram -- Type A waste treatment.

Blend/Surge Storage (Figure 17) --

The four 50,000-gallon stirred tanks will provide the capacity for blending treated wastes to produce a uniform feed for the downstream precipitation step. With nonreactive waste bypassed, the surge capacity will provide for independent filling and emptying of the tanks during the two-shift operation.

Waste Precipitation and Filtration (Figure 18) --

Precipitation of metal hydroxides will be carried out in two parallel trains. Blended waste from the surge tank will be pumped into the 3,000-gallon stirred precipitation vessel. Calcium hydroxide (25% slurry) will be added to the vessel on pH control, while maintaining the pH at 8 to coprecipitate heavy metals. Precipitated slurry waste will be pumped on makeup level control to a rotary vacuum belt filter system. Ferric chloride (35%) solution will be metered into the flocculation trough as a coagulant aid. The 12-foot-diameter by 24-foot-long vacuum filter will continuously dewater the precipitated waste, producing a 40 percent weight solids filter cake. The cake will be discharged into a bin from where it is transferred by screw conveyors to a 150-ton-capacity cake surge bin. The filtrate collected will be pumped from the vacuum receiver tanks to filtrate storage tanks for subsequent processing. Each precipitation-filtration train can process about 325 tons of blended waste during two shifts, producing 75 tons of filter cake for containerization. Waste treatment will be carried out in the waste treatment building as indicated in Figure 15. Processes will be monitored locally and in the main control room.

Type B Waste Processing

Four hundred tons of Type B wastes will be received daily. Type B waste subtypes will include 50 TPD each of acid and alkaline wastes (B-1), 200 TPD of inorganic wastes (B-2), and 100 TPD of organic wastes (B-3).

Waste Receiving and Storage (Figure 19) --

Any of the subtype wastes can be transported to the plant in bulk form and in 55-gallon drums. Type B waste unloading and storage procedures will be similar to those for Type A wastes. Unloading stations for rail and truck shipments will be located near Type A waste unloading stations so that unloading crews can handle both wastes. Positive displacement slurry pumps will be used for transferring wastes to the storage tanks. Storage tanks will have 25,000- and 50,000-gallon capacities and side-entering agitators for mixing. The organic waste tanks will have steam heating coils to prevent waste solidification during cold weather.

Type B Waste Treatment (Figure 20) --

Type B wastes will be dewatered to recover the insoluble solids as filter cakes. Acid and alkaline wastes (B-1) pumped from the storage tanks will first be neutralized in a 900-gallon stirred tank. Calcium hydroxide (25% slurry) will be added on pH control to neutralize excess acidity.

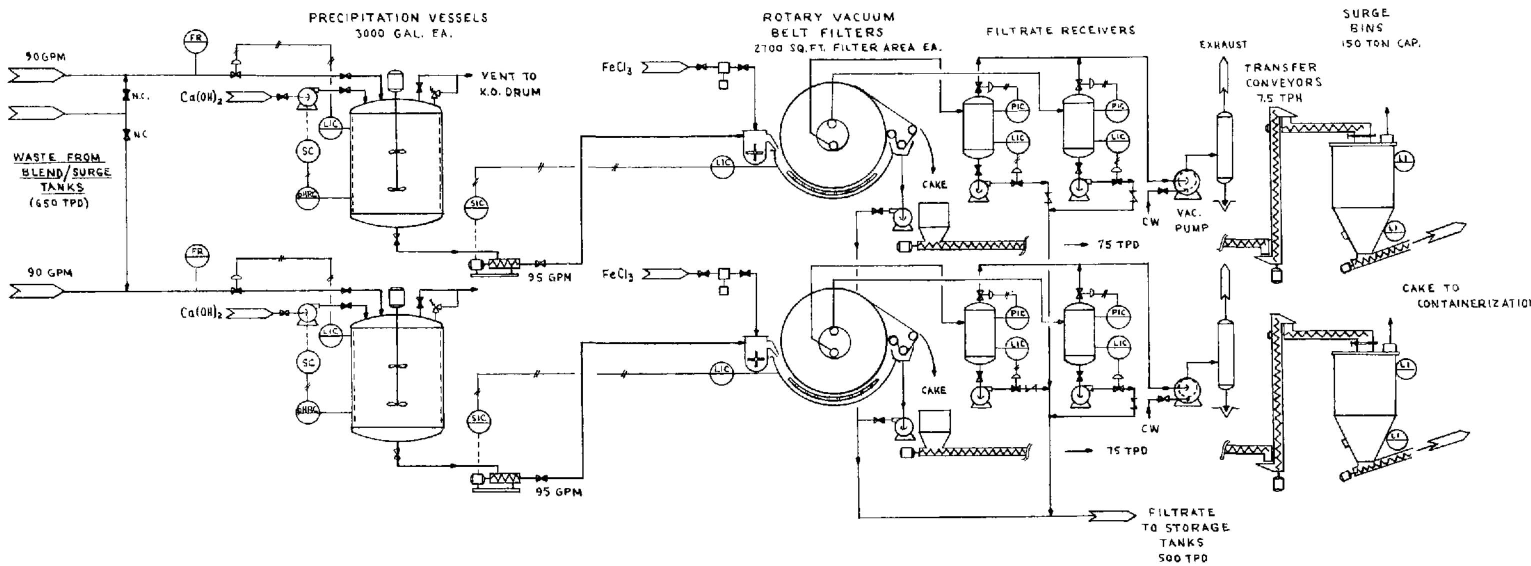


Figure 18. Process flow diagram -- Type A waste precipitation and filtration.

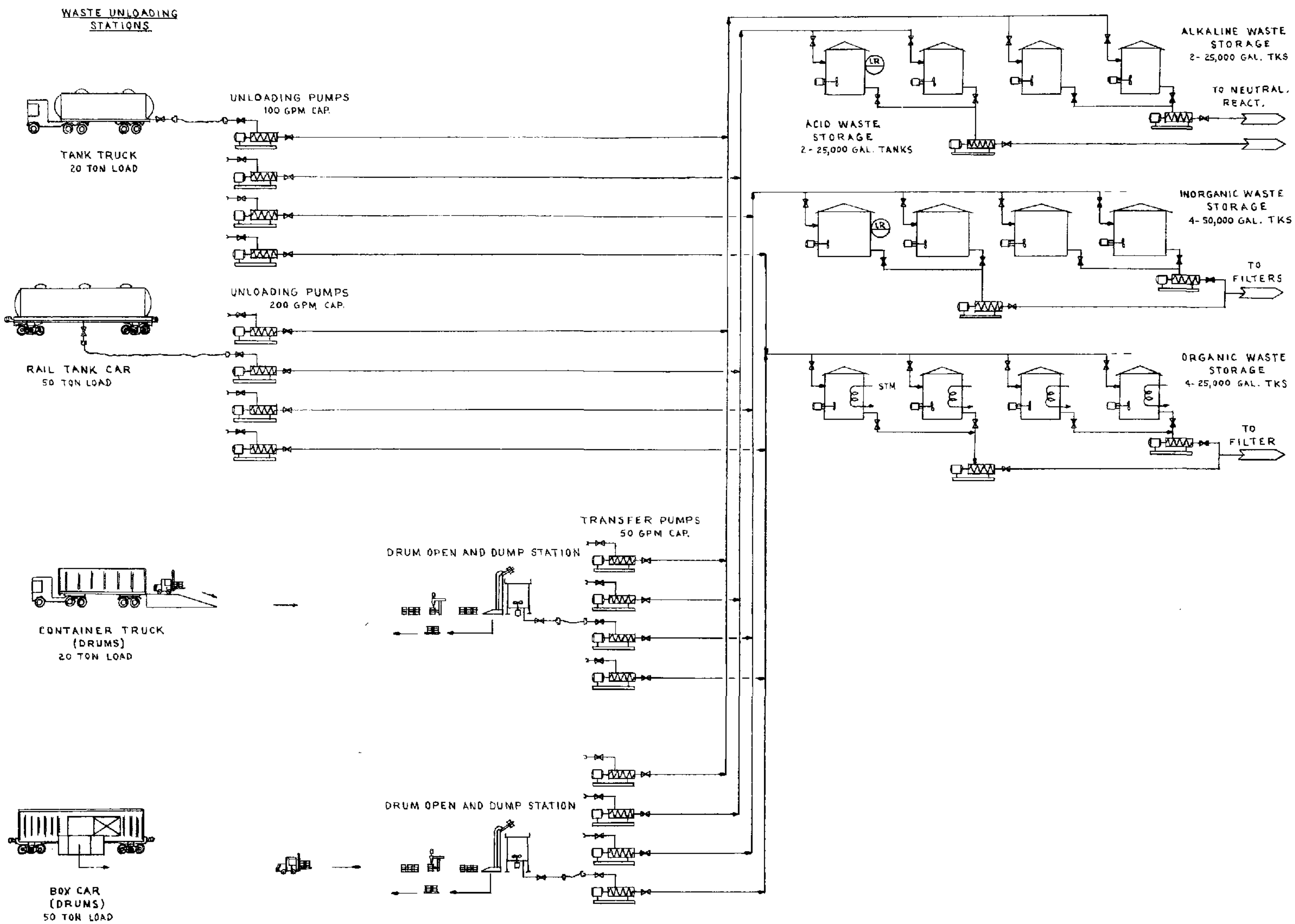


Figure 19. Process flow diagram -- Type B waste unloading and surface storage.

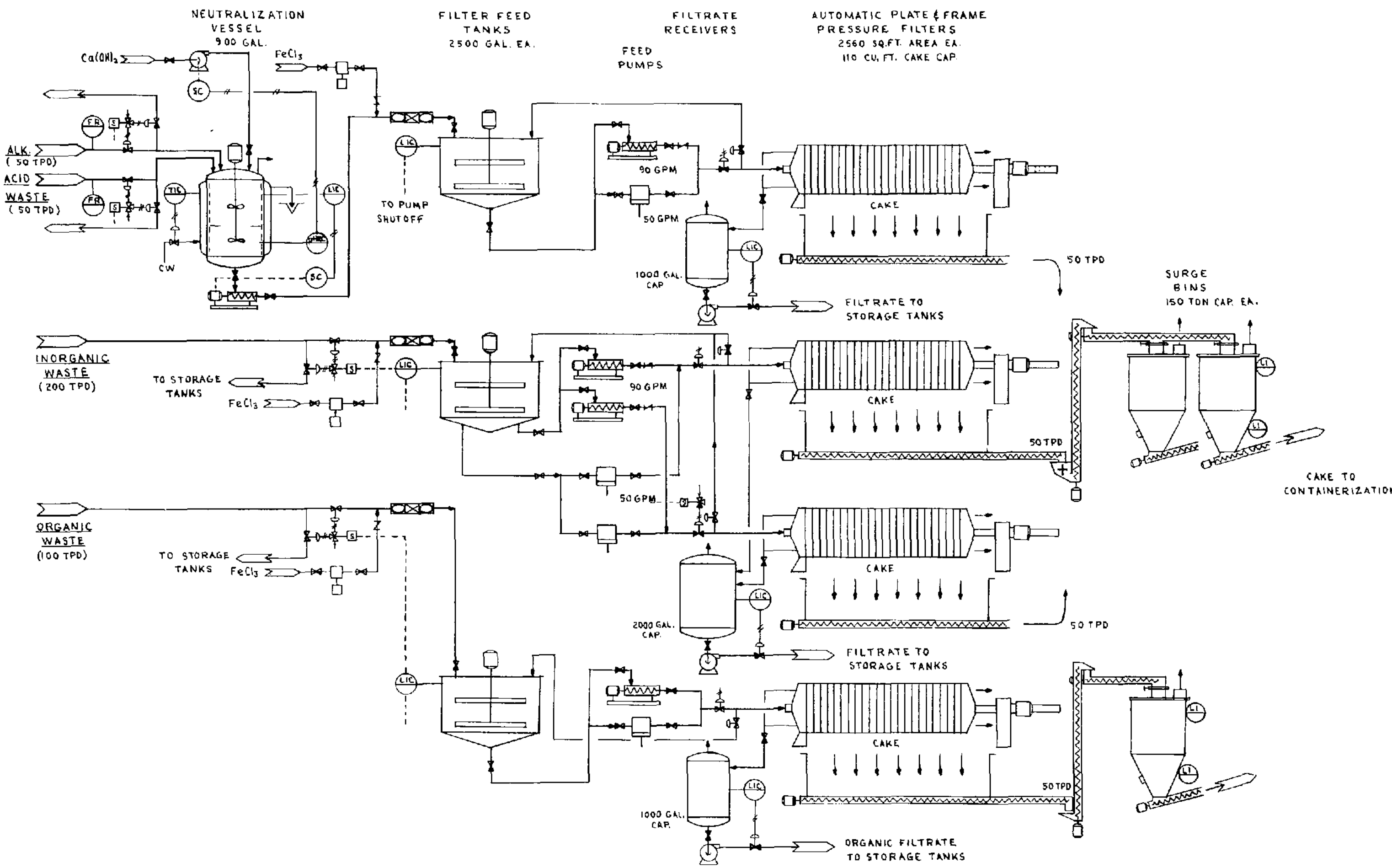


Figure 20. Process flow diagram -- Type B waste treatment and filtration.

Neutralized waste will be pumped to the filter feed tank. Ferric chloride flocculant will be added in an on-line static mixer. Filtration will be carried out cyclically in an automatic plate and frame pressure filter. At the start of the filtration cycle, slurry waste will be pumped into the filter chambers by the fast-fill pump. As the cake forms, the hydraulic ram pump will be used to consolidate the cake during the high pressure (to 150 psi) dewatering phase. At the end of the preset filtration time (up to 90 minutes), the feed pump will shut off, and the plate opening mechanism will separate the plates, allowing the cake slabs to drop into the filter cake bin. The cake will be transferred by screw conveyors to a 150-ton cake surge bin. The plate closure mechanism will move the plates back together so that plate pressure against the filter cloths seals the chambers and the next cycle can be initiated. The filtrate collected during the filtration cycle will be pumped from a receiving tank on level control to a filtrate storage tank.

Inorganic and organic wastes will be dewatered in similar filtration systems. Inorganic waste will be pumped from the storage tank on filter feed tank makeup level control. Ferric chloride flocculant will be added to the waste stream ahead of an in-line static mixer. The waste will be dewatered in two automatic pressure filters operated with staggered filtration cycles. Organic waste will be dewatered in a separate automatic filter system. Organic filter cake will be transferred by screw conveyors to a separate 150-ton cake surge bin. Organic filtrate will be pumped to the oily waste storage tanks. Each of the four 4 by 4 feet by 80-chamber pressure filters can process about 100 tons of waste during two shifts, producing 50 tons of filter cake (40 percent solids) for containerization. A spare filter system can be piped to operate on either organic or inorganic waste. One hundred and fifty tons per day of inorganic filtrate and 50 tons per day of organic filtrate can be produced. Filtration conditions will be based on analysis of the wastes in the storage tanks and lab filtration tests.

<u>Type C and D Waste Processing (Figure 21)</u>

Two hundred and fifty tons of Type C wastes and 50 tons of Type D wastes will be received daily. Type C wastes will be transported in bulk by covered hopper rail car and by covered dump truck. Type C and D wastes in drums will be transported by box cars and by container truck. After weigh-in and inspection, a dump truck of Type C waste will be routed to the dump station. Waste discharged into the shrouded dump pocket will be transferred by screw conveyors to one of six bulk storage bins (150-ton capacity each). A hopper car of Type C waste will be spotted at the rail dump station. The waste will be transferred from the dump pocket to the storage bins by a screw conveyor system. Organic and inorganic wastes will be stored in separate bins. The self-cleaning screw conveyors will prevent gross mixing of the two waste types. Each storage bin will be equipped with a filter fabric dust collector, bin level indicators, and a vibrating hopper. Waste will be transferred by screw conveyor from a full bin to the desired surge bins for subsequent containerization. The six-day storage capacity will allow for independent filling and emptying of individual bins. Two bins will be provided for organic wastes.

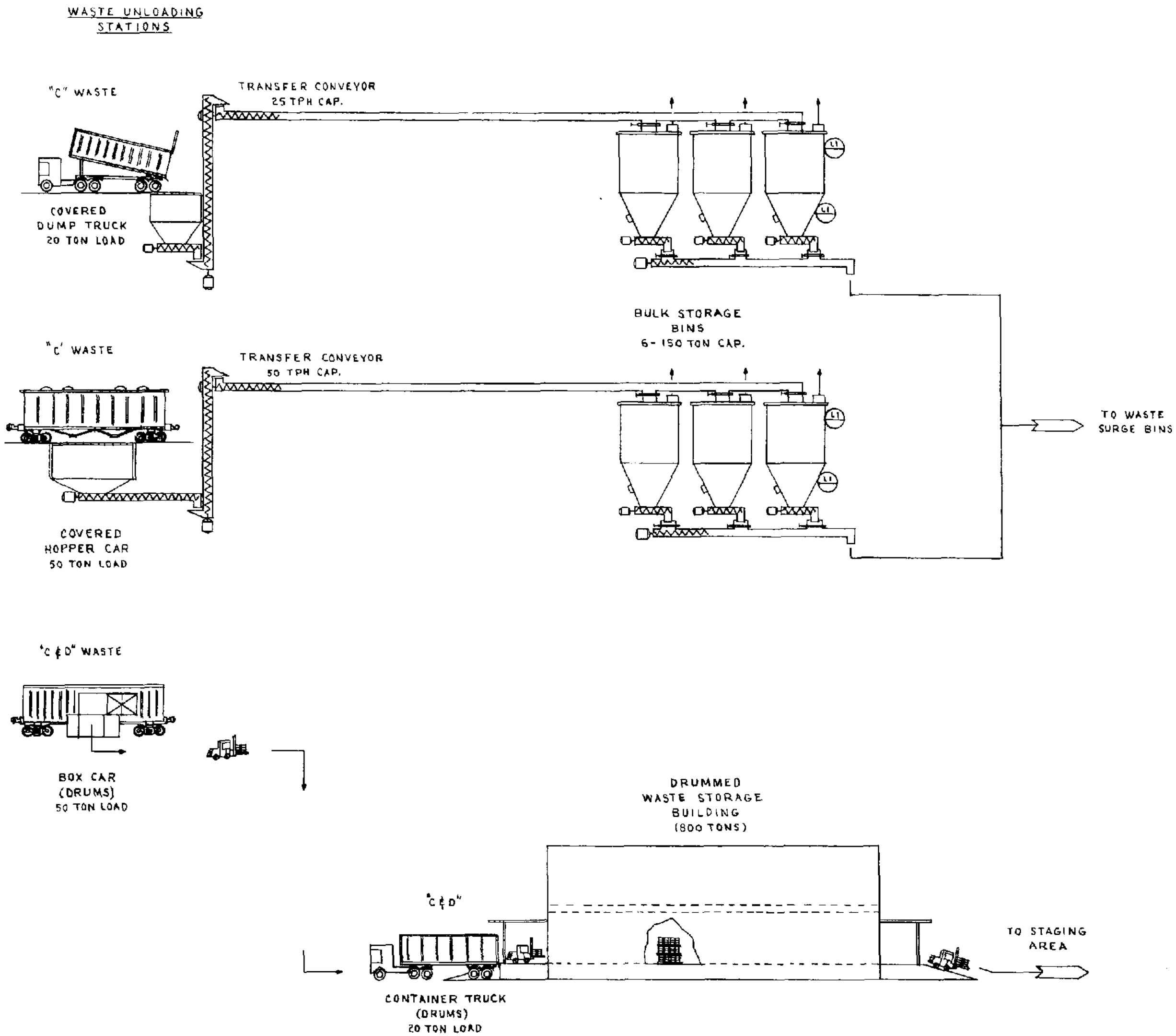


Figure 21. Process flow diagram -- Types C and D waste unloading and storage.

Type C and D drummed waste in box cars will be unloaded by forklift trucks and transported across to the lower level of the drummed waste storage building. Container trucks with Type C and D wastes will be unloaded by forklift trucks at the waste storage building receiving dock (Figure 15). The drums will be stored in designated pallet banks. Type C wastes will be segregated from Type D wastes, and each then further subdivided into organic and inorganic storage banks. Drums in storage will be relabeled before transfer to the staging area for lowering into the mine. The eight-day storage capacity will allow some flexibility in rescheduling waste lots for emplacement when difficulties occur in waste treatment or containerization operations. Type C and D waste unloading will normally be a one-shift per day operation.

Chemical Feed Systems (Figure 22)

A number of chemicals will be used in Type A and B waste treatment systems. The chemical unloading and storage area is indicated in Figure 22.

Chlorine --

Chlorine will be received and stored onsite in a 90-ton tank car. During operation of the cyanide oxidation process, liquid Cl_2 will be withdrawn and vaporized in four parallel evaporation units. Gaseous chlorine will be fed to each of the two cyanide oxidation reactors. The tank car will provide a 10-day supply of chlorine at normal usage. As necessary, tank cars will be switched during the third shift.

Sulfur Dioxide --

Sulfur dioxide will be received and sorted onsite in a 30-ton tank car. During operation of the chromate reduction process, liquid SO_2 will be withdrawn from the tank car and evaporated in an electrically heated evaporation unit. Gaseous SO_2 will be fed on ORP control to the chromate reduction reactor. The tank car will provide a 12-day supply of SO_2 at normal usage. Empty and full tank cars will be switched during the nonoperating (third) shift.

Sodium Hydroxide --

Fifty percent sodium hydroxide will be received in 60-ton tank cars and pumped into one of two 10,000-gallon storage tanks. Caustic will be pumped from storage to the cyanide oxidation reactors during the operating shifts. The storage tanks will provide eight days of storage capacity at the normal rate of caustic usage.

Lime --

Calcium hydroxide will be used for neutralization of Type A and B acidic wastes and for precipitation of Type A wastes. Lime will be slaked onsite and diluted to a 25% $Ca(OH)_2$ slurry. Pebble lime (90% CaO) will be received in a 70-ton rail hopper car and dumped in the car dump pocket. The lime will be transferred by the enclosed conveyor system to one of two 100-ton lime storage bins. Lime will be charged to the slaker by a weigh-belt feeder.

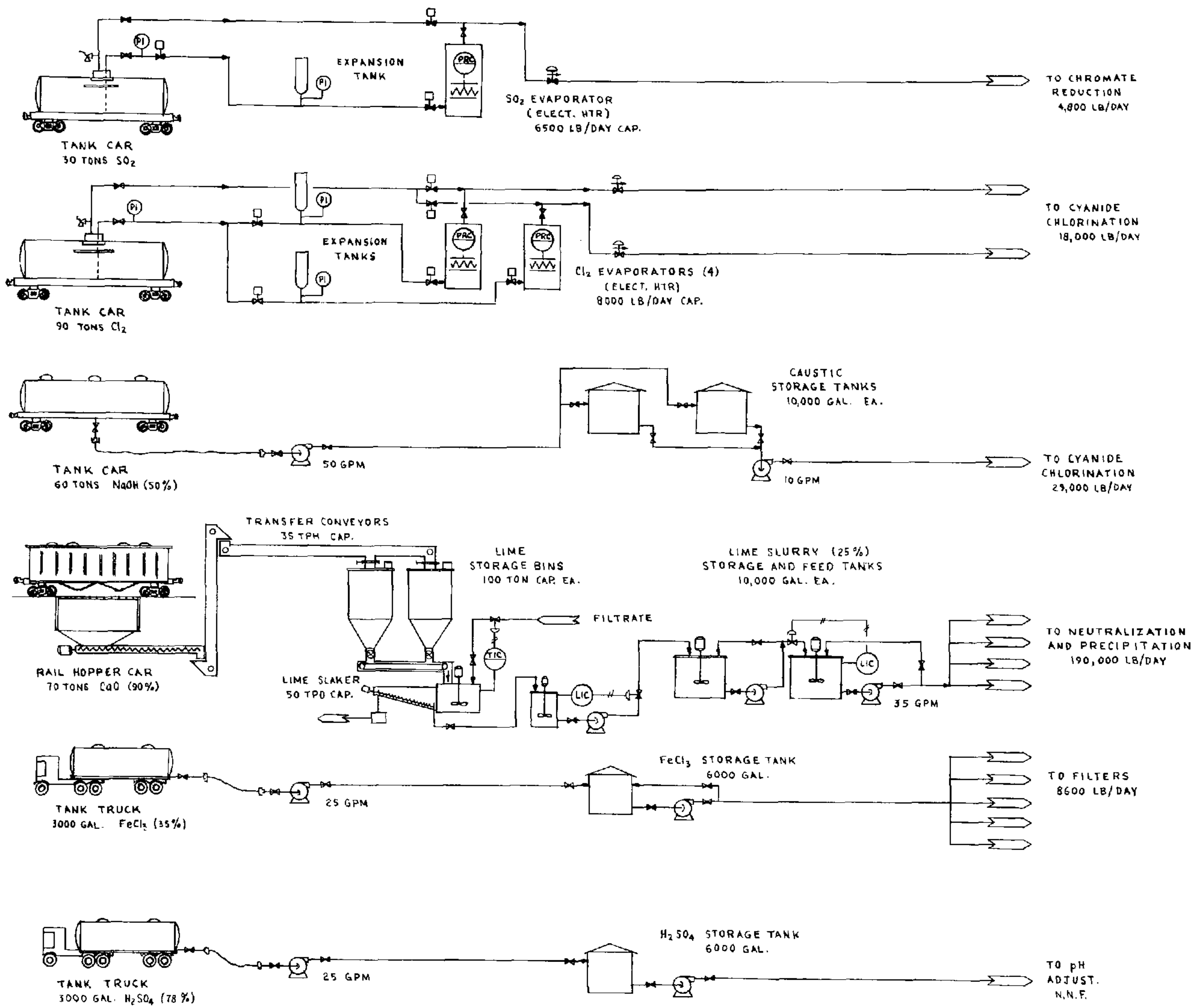


Figure 22. Process flow diagram -- chemical unloading and surface storage.

Slaked lime slurry will be discharged to a transfer tank from which it is pumped to the lime slurry storage and feed tanks. Slurry will be pumped through the distribution system to the various processes. The 10,000-gallon storage and feed tanks will provide a one-day supply of $Ca(OH)_2$ slurry. The lime storage bins will provide a 10-day supply of lime at normal usage.

Ferric Chloride --

Ferric chloride will be used as a filter aid in Type A and B waste filtration systems. Sewage-grade (35%) ferric chloride solution will be received in 3,000-gallon tank trucks and transferred to a 6,000-gallon storage tank. During the operating shifts, $FeCl_3$ will be pumped from storage through the distribution system to the various filters. The storage tank capacity will provide a two-week supply at normal usage.

Sulfuric Acid --

Sulfuric acid will be used for pH adjustment of Type A-1 waste prior to chromate reduction. Sulfuric acid (78%) will be received in 3,000-gallon tank trucks and pumped to a 6,000-gallon storage tank. As needed, sulfuric acid will be pumped from storage to the pH adjustment vessel. The storage tank capacity will provide a one-month supply.

Plant Effluent Treatment (Figure 23)

Contaminated effluents from waste processing operations will include 650 TPD of inorganic filtrate, 150 TPD of process and utility wastewater, and 50 TPD of organic filtrate. Contaminated runoff from process areas will be an intermittent effluent. Effluent waste treatment systems will operate three shifts per day.

Inorganic Effluent Treatment --

Inorganic (aqueous) filtrates will be collected in two 175,000-gallon storage tanks. Process and utility wastewaters will be collected by gravity in a 50,000-gallon lined basin. Process wastewater will include water from drum cleaning, equipment cleanout and decontamination, floor and unloading area washdowns, lab wastes, and any water pumped from the mine. Utility wastewater will include cooling tower blowdown, utility boiler blowdown, flue gas scrubber blowdown, pump seal water blowdown, and minor amounts of steam condensate.

The aqueous effluents will be treated in an evaporation-crystallization system. Process and utility wastewaters will normally be worked off with the inorganic filtrate.

Wastewater will be pumped from the storage tank on flow control to the vapor-recompression evaporator unit (150 gpm capacity). The purpose of the unit is to produce a concentrated brine stream (about 33% solids) by evaporating part of the water and collecting it as condensate.

The vapor-recompression evaporator unit is a package system in which

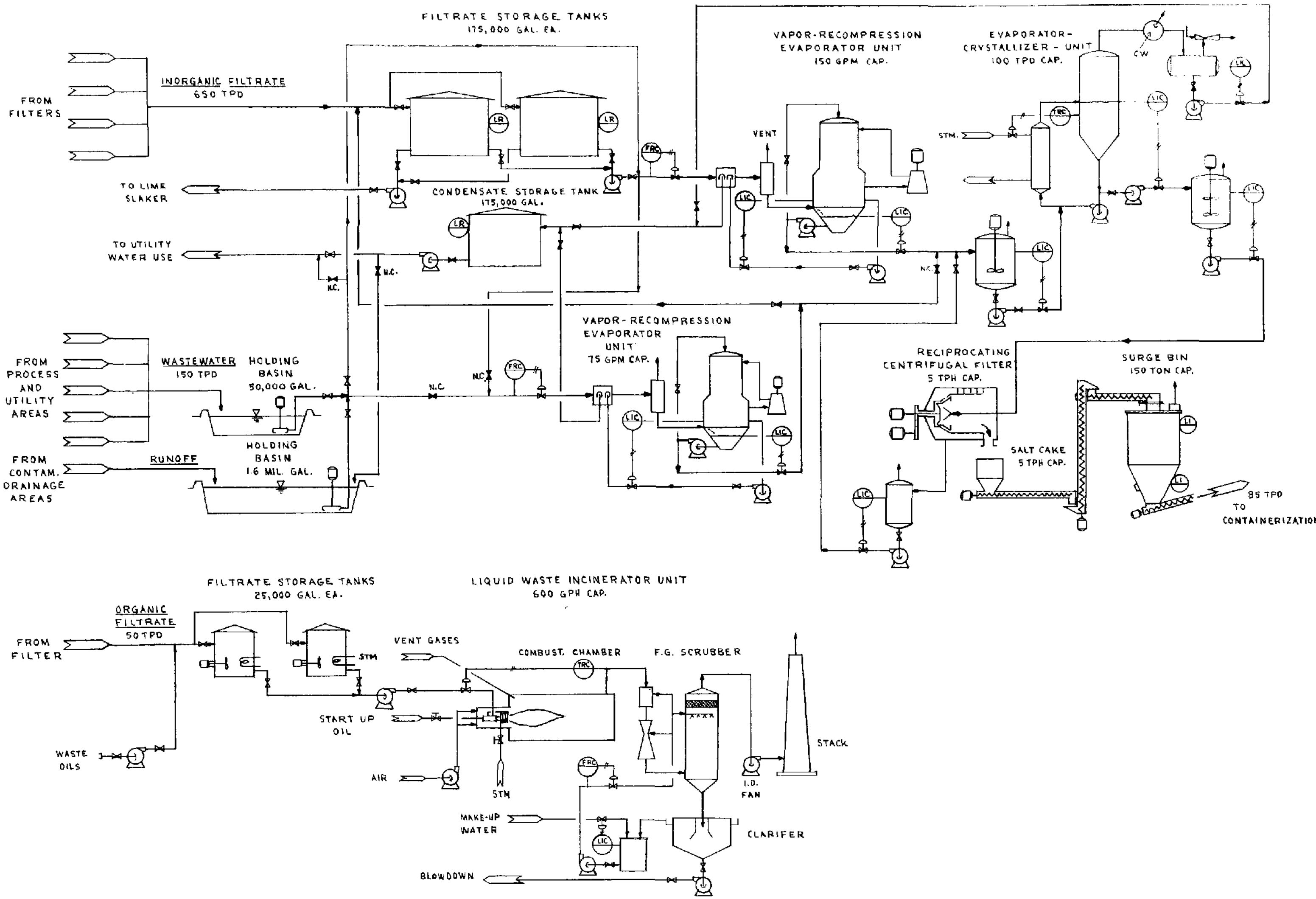


Figure 23. Process flow diagram -- plant effluent treatment.

the feed will be combined with the brine in the sump of the evaporator and then the mixture fed to the top of the evaporator for evaporation-concentration process. Heat for the evaporation will be obtained from condensation of recompressed vapor. Part of the concentrate will be discharged as brine product and pumped to the crystallizer. The total energy requirement for evaporation will be 70-100 kilowatt-hours per 1,000 gallons of water evaporated.

About 70 percent of the feed will be recovered as condensate. The condensate will be stored in a 140,000-gallon tank for possible reuse in the plant, such as cooling water makeup and boiler feedwater makeup. Excess condensate will be discharged into the plant sanitary wastewater sewer.

Hot brine product will be pumped on level control to a stirred surge tank ahead of a forced circulation evaporator-crystallizer unit. This unit will be used to crystallize dissolved solids by evaporating water. Salts come out of solution as their solubility limits are exceeded. The crystallizer is also a package system (100 TPD capacity), in which water will be evaporated from a circulating feed-slurry mixture producing slurry and condensate.

Crystallizer slurry product will be pumped to the feed tank ahead of the centrifuge filter. The slurry will be filtered in a 5 ton per hour reciprocating centrifuge filter. Salt cake will be discharged into a cake bin continuously and transferred by screw conveyors to a 150-ton surge bin for subsequent containerization. Eighty-five tons per day of salt cake will be produced. Saturated filtrate will be pumped back to the evaporator-crystallizer feed tank for reprocessing.

A 75 gpm vapor-recompression evaporator unit will be used intermittently to evaporate contaminated storm runoff. The small quantity of brine produced can be sent to the 150 gpm vapor-recompression evaporator or to the evaporator-crystallizer. This 75 gpm unit will also serve as a 50 percent capacity spare for working off inorganic filtrates and process wastewater when the larger unit is down for maintenance. Prolonged shutdown of any of the units would require shutdown of waste processing units. The large stormwater basin will provide emergency storage capacity.

Organic Effluent Treatment (Figure 23) --

Organic filtrate will be collected in two 25,000 gallon storage tanks. The tanks will be equipped with steam coils to maintain the contents pumpable. The filtrate and small amounts of waste lubricating oils will be burned in a 600-gallon-per-hour package-type liquid waste incinerator. Oil will be used as fuel for startup. Hot flue gas will be cooled and scrubbed with water in a venturi scrubber.

The organic effluent incinerator is a package system (600 gallons per hour capacity) consisting of feed pump, incinerator, and scrubber system. Blowdown from the scrubber system will be pumped to the inorganic effluent treatment system.

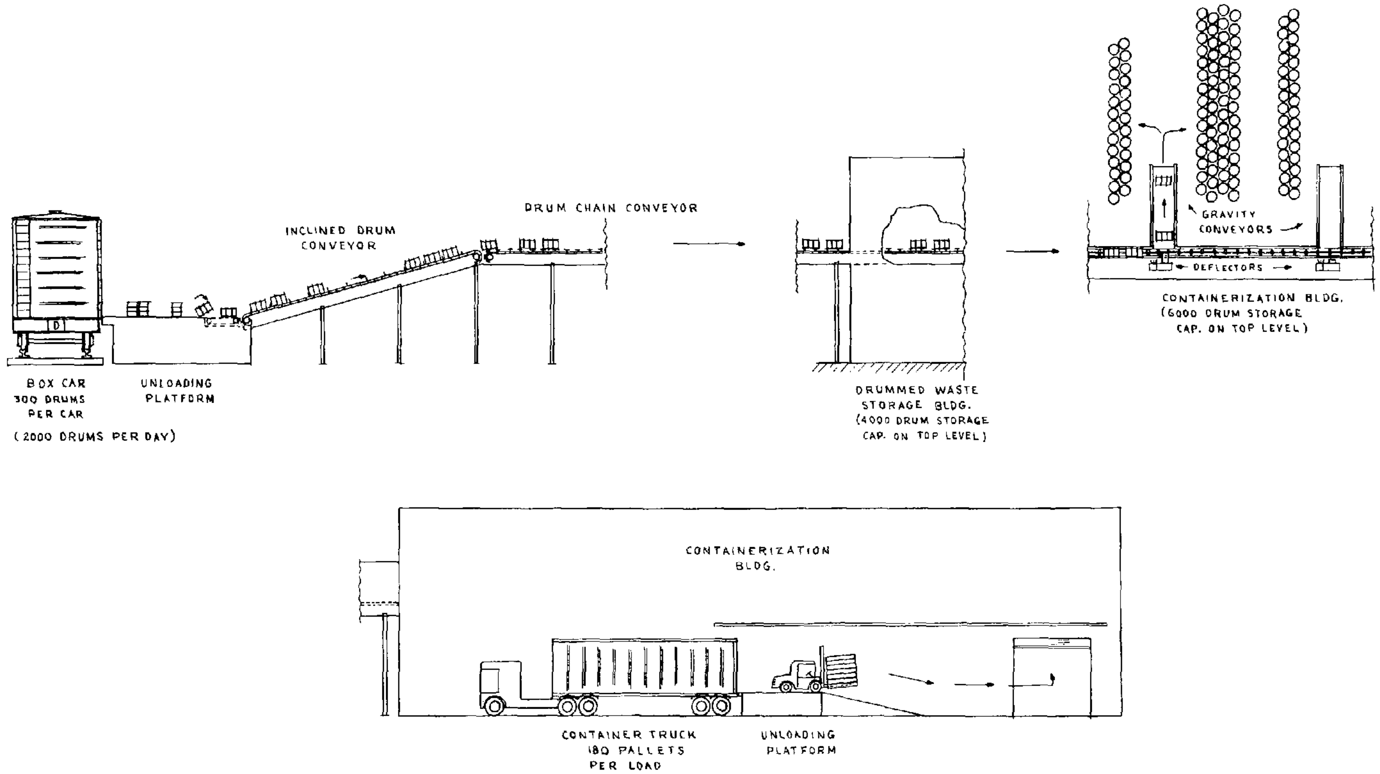


Figure 24. Process flow diagram -- container unloading and surface storage.

Waste Containerization and Staging

Five hundred and eighty-five tons of waste will be put in 55 gallon drums during two shifts of operation. About 2,000 drums and 500 wood pallets will be used in containerization each day. Palletized drums of waste will be transferred to the staging area prior to emplacement in the mine.

Drum and Pallet Receiving and Storage (Figure 24) --

Fifty-five gallon, open-top steel drums will be brought to the plant in box cars. After a car is spotted at the receiving platform (Figure 15), the drums will be unloaded and placed horizontally on a feed conveyor, which will transfer them to an inclined conveyor and to an elevated drum chain conveyor, all enclosed. The chain conveyor system will run through the upper level of the drummed waste storage building and on to the upper level of the containerization building. Drums will be stored in the upper level of both buildings.

As needed, the drums will be transferred to the lowering conveyors in the containerization building after removal of the drum covers. Up to 10,000 drums can be stored (5-day supply).

Heavy duty wood pallets will be shipped in by container truck. At the unloading platform outside the containerization building, a forklift truck will be used for unloading the pallets and stacking them in the containerization building (lower level). The pallets will subsequently be taken from storage and loaded in the automatic pallet loaders. Damaged pallets from waste unloading and storage operations will be hauled away as scrap wood.

Waste Containerization (Figure 25) --

Type A and B waste filter cake, Type C bulk solid waste, and salt cake from effluent treatment will be containerized in drums. Six drum filling lines will normally be used, each fed waste from a surge bin located outside the containerization building. Type C bulk wastes will be distributed to the various surge bins as necessary to maintain feed supply to drum filling lines.

A typical drum filling operation is indicated in Figure 25. Empty drums on the upper level will be fed into a conveyor that automatically loads the arm lowering conveyor. Drums are lowered to the first floor of the containerization building and transferred to the drum-fill station. An indexing conveyor will move each drum sequentially into and out of the drum-fill station. At the drum-fill station, waste from a small surge bin will be fed into the drum until a preselected total weight is reached (normally 625 lb net). The scale will electronically shut off the vibrating feeder and will signal the indexing conveyor to move the drum out and another into position.

Filled drums will be sequentially indexed into and out of the drum close and label station. At the drum close station, the drum cover will drop on to the drum, and the lever-snap ring is manually closed and locked. A drum labeling machine will stencil the waste type, date, and drum number on the side of the drum. The closed, labeled drums will be indexed onto an accumu-

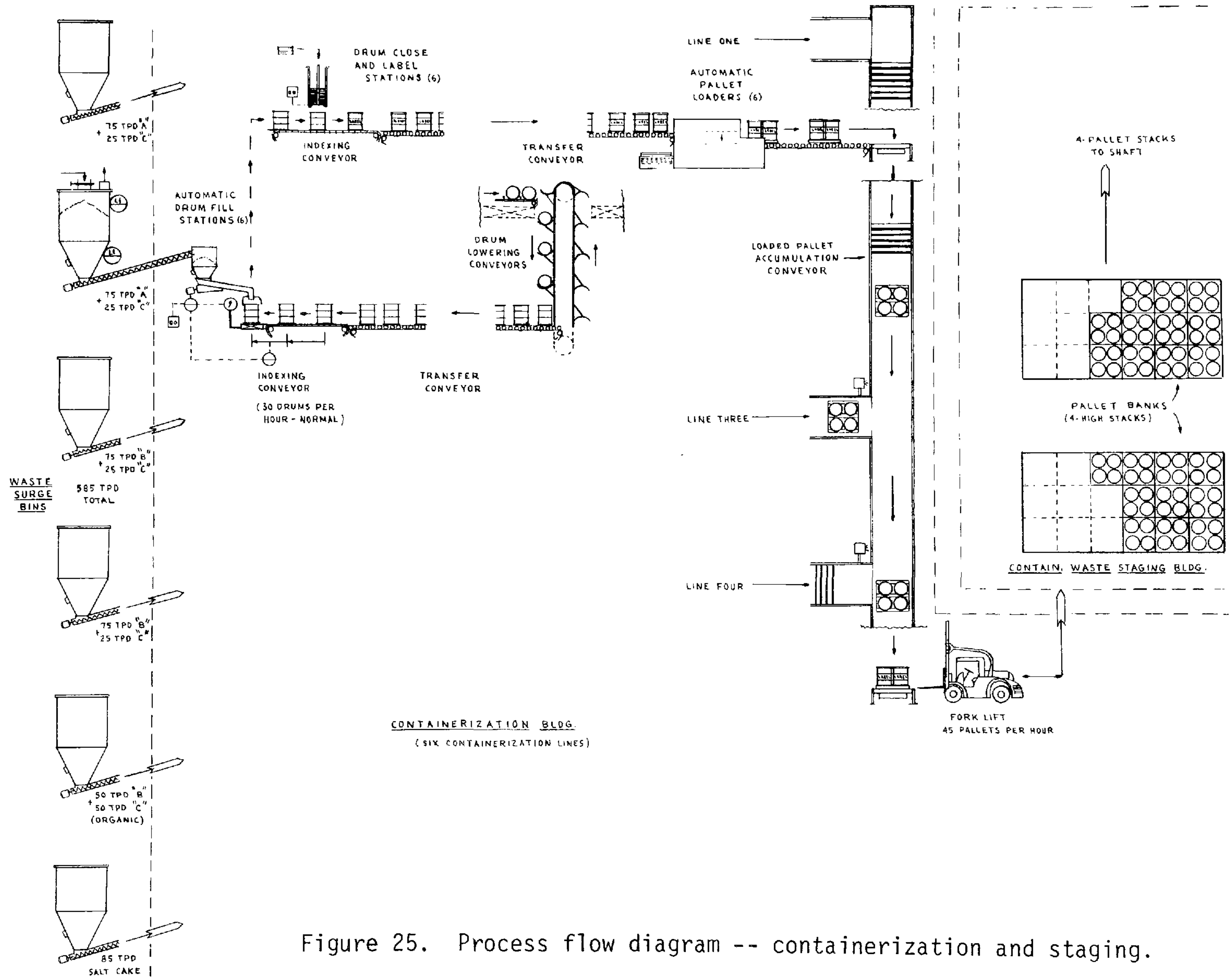


Figure 25. Process flow diagram -- containerization and staging.

lation conveyor, which will transfer the drums to the automatic pallet loader. When the four drums have been positioned on a pallet, the pallet will be lowered onto a transfer conveyor. Loaded pallets from each of the six containerization lines will be collected on an accumulation conveyor from which forklift trucks will pick them up for transport to the waste staging building. Although waste containerization will be largely automated and worker contact with the waste will be small, it will be necessary that the operating personnel wear protective clothing and filter masks where contact with the wastes is possible.

Surface Staging --

The waste staging building will be located at the production shaft (Figure 15). Waste staging and scheduling will be coordinated with subsurface personnel responsible for scheduling waste storage. Loaded pallets from the containerization building will be stacked four-high in designated areas of the staging building. The drums will be segregated in pallet banks according to the emplacement designation of waste types, i.e., organic, inorganic, and retrievable.

Only one of the four types of waste will normally be lowered into the mine during a shift. This will allow shipments to be made to only one area at a time. For example, organic wastes will be allowed to accumulate in the staging area until a shift's worth of production is available. Retrievable wastes (Type D) will normally be lowered into the mine during one shift a week. They will not usually be stored in the staging area, but will be transferred from the waste storage building directly to the production shaft area. Drummed Type C wastes will normally be worked off in a similar manner.

Surface Site Development and Buildings

The layout of the surface civil structures and buildings are shown in Figure 15. Except for the production shaft and some portion of the railroad tracks, all surface civil structures and buildings will be new. Of the total 17 acres of the fenced surface area, 15 acres are within the present mine boundary and 2 acres have to be purchased from the local residents.

Approximately 13 acres of land will have to be cleared, including all of the existing buildings except the production shaft. New civil structures and buildings will be:

- Truck scale office and pad
- Rail scale office and pad
- Tank truck unloading platform
- Container truck unloading platform
- Dump truck unloading building
- Tank and hopper car unloading building
- Box car unloading platform
- Drum unloading platform
- Chemical unloading platform
- Chlorine unloading platform
- Storage tank area

- Drum waste storage building
- Waste treatment building
- Filtration building
- Containerization building
- Staging building
- Administration building
- Safety/medical building
- Laboratory
- Equipment storage building
- Warehouse
- Shops
- Drum cleaning building
- Wastewater collection ponds
- Wastewater treatment and filtration building
- Boiler house

Description of these facilities and their costs are summarized in Appendix D.

Surface Utilities

A boiler, cooling tower, electric system, compressed air system, drainage system, and yard safety such as fire protection systems and washdown stations will be included in the surface utility. Their general specifications and costs are shown in Appendix C. The boiler and cooling tower will be primarily for the wastewater treatment process.

Surface Treatment Problems

To develop the conceptual design of surface facilities, numerous assumptions and simplifications had to be made on the waste characteristics, waste treatability, reaction rates, and properties of wastes at various process stages. Considerably more would need to be known about the handling properties of received wastes, their chemical characteristics, and their reaction rates before a reliable plant could be constructed. Some of the potential problem areas are discussed here.

Waste Receiving and Unloading --

Compatibility of the wastes is an important factor that will affect the number of unloading stations, the number of transfer pumps, piping, and conveyors, and the number of storage tanks and bins. The more varied the wastes (chemical and physical characteristics), the more extensive the receiving and storage facilities will have to be. The trucks and railcars would need to be decontaminated within the plant, accepting and treating all of the contaminated water. The cost, both in manpower and equipment, could be very high.

It may be difficult to mix adequately sludge and slurry wastes in large storage tanks. Mixing is needed to prevent solids from settling to the bottom of the tank where they cannot be easily resuspended. When the liquid level falls below the agitator impeller, settling out will occur. Prolonged failure of an agitator (power outage) could result in mud cakes that cannot be resuspended. The tanks might be equipped with jet-nozzle systems to reslurry and pump out mud cakes. Plugging of pump suction lines may be minimized by routinely back-flushing the lines prior to pump startup.

The liquefaction of bulk solids in storage bins will depend on the properties of the various solid wastes, their moisture contents, and even the ambient temperature. The bins should have vibrating hoppers and other devices to reduce solids bridging and assist material flow out of the bin. In winter, freezing of material on bin walls could hinder or prevent flow of material out of a bin. Use of steam guns to assist thawing may be needed, or the bins could be equipped with external strip heaters and insulation.

In unloading drummed wastes, drums may be punctured or dropped causing leaks of waste onto floors or yard areas. Cleanup and decontamination efforts will result in unloading delays. Cleanup operations will have to be well planned and carefully supervised for worker safety.

Waste Treatment --

Again, the wide variety of wastes may dictate more types of treatment than were included here, and consequently more equipment and a more complex operation. It would seem prudent that any single facility should not attempt to handle every kind of hazardous waste, since it could not do so economically.

With these basic treatment methods, problems are most likely to be the results of malfunctions - either mechanical or instrumentation. In the reaction steps, overtreatment could result in vent gases containing SO_2 or chlorine that would have to be scrubbed out. If volatile materials were present in the wastes, they may be stripped and appear in the vent gases. Undertreatment could result in potentially reactive material being handled in downstream steps and being placed in the mine. Reactor products will have to be carefully analyzed and reprocessed if incomplete reactions occurred.

Filtration will likely be a problem area in design and operation. Filtration rates and cake solids contents are highly dependent on the physical and chemical properties of the wastes. The average 40 percent solids content used here may in practice represent the long-term average where the day-to-day variation is, say, 10 percent to 80 percent. Such variations would create difficult problems in downstream operations. Variations in the handling properties of the filter cakes could make the transfer conveyors, storage bins, and feeders difficult to design and operate.

Wastewater Effluent Treatment --

The inorganic filtrate evaporation and mixed salt crystallization processes should have the capability of handling a wide range of feed solids concentrations. Processing problems may include scale formation on heat transfer surfaces, foaming caused by surface active chemicals, and perhaps low-temperature polymerization of organic materials present in the filtrates.

Again a knowledge of the feed material and its variability in the design stage, can help to minimize processing problems. The 24-hour a day system has the vulnerability that a prolonged major equipment failure will shut down the upstream treatment processes. If high reliability cannot be assured, then extensive spare capacity should be provided.

Disposal of excess condensate could be a problem if volatile hazardous materials are present in the feed. Some additional treatment, e.g., activated carbon adsorption or ion exchange, may need to be considered for polishing the condensate.

The incinerator system is not intended to burn hazardous organic materials. For organic filtrates containing chlorinated hydrocarbons, there is a potential for formation of phosgene ($COCl_2$), if combustion conditions are not well controlled. There is also the possibility of polymerizing organic material in the combustion or post combustion zones. Again, with well defined feed characteristics in the design, processing problems can be minimized.

Waste Containerization --

Containerization is essentially a large packaging operation. Empty drum handling is labor intensive in order to reduce the damaging of drums ahead of containerization. Bent drums may buckle when filled and stacked, and drum covers may not fit on out-of-round drums. Drum handling and storage requirements could be reduced by onsite fabrication.

The drum-filling operation is susceptible to over- and underfilling of drums, if bulk densities of the wastes are highly variable. Fill weights should be easy to adjust. Alternatives are automatic volumetric filling and manual filling by observation. The automatic conveyor system should be very reliable, but a malfunction will shut down an entire line.

Before drums are taken to the staging area, they will have to be carefully inspected for structural integrity. Mechanical handling and the movement by forklift trucks can be expected to result in damaged drums. These will have to be taken off the line and recontainerized -- probably a manual operation.

It may be advisable to strap the drums together on the pallets to minimize drum movement and shifting on the pallets during subsequent handling operations.

SUBSURFACE FACILITIES

Existing mine facilities are described in detail in Section 3. Description of new underground facilities and rehabilitation of existing facilities are discussed in this section. An overview of the subsurface operation is shown in Figure 26. The subsurface facilities and their operation will be described with the aid of Figures 27 through 33. Lists of underground equipment, service buildings, and operating personnel are shown in Appendices C, D, and E.

Although a wide variety of wastes (four types and seven subtypes) will be processed at the surface facilities, when the wastes are ready to be transported into the mine they will all be in drums of the same specification. These drums are divided into three groups designated for separate storage (Figure 5). This includes:

- Storage Zone X for 535 TPD of inorganic wastes (Type A - 150 TPD; Type B - 150 TPD; Type C - 150 TPD; WW solids - 85 TPD).

- Storage Zone Y for 100 TPD of organic wastes (Type B - 50 TPD; Type C - 50 TPD).

- Storage Zone Z for 50 TPD of wastes to be retrieved (Type D - 50 TPD).

The daily loading rates shown above are a long-term average figure. In actual operation, the storage operation will be scheduled so that the same group of wastes will be lowered and stored during any one shift.

This will include approximately nine shifts per week for inorganic wastes, two shifts per week for organic wastes, and one shift per week for wastes to be retrieved. All subsurface facilities are operated two shifts per day and six days per week. The maintenance work is done during the third shift.

The subsurface operation will start with the transfer of drummed wastes from the surface staging area to the production skip in the same building. The subsurface operation will include:

- Surface loading and lowering into mine
- Underground unloading and staging
- Haul to storage zones
- Storage
- Storage cell preparation
- Monitoring
- Record keeping

Surface Loading and Lowering into Mine

The surface loading operation will consist of transferring four pallets (16 drums) from the surface staging area to the production skip in the same building and placing them on the skip. Forklift trucks will be used to handle the pallets (Figure 27). A utilityman (laborer) stationed at the shaft will secure the load and signal that the load is ready for lowering.

On the average, 70 lowering cycles will be performed in each shift. Each cycle will take 5 to 7 minutes, which includes 1.5 minutes of actual lowering time and the remaining for loading and unloading. The surface loading will involve three forklifts and four operating personnel in each shift. Detailed lists of equipment and personnel are shown in Appendices C and E.

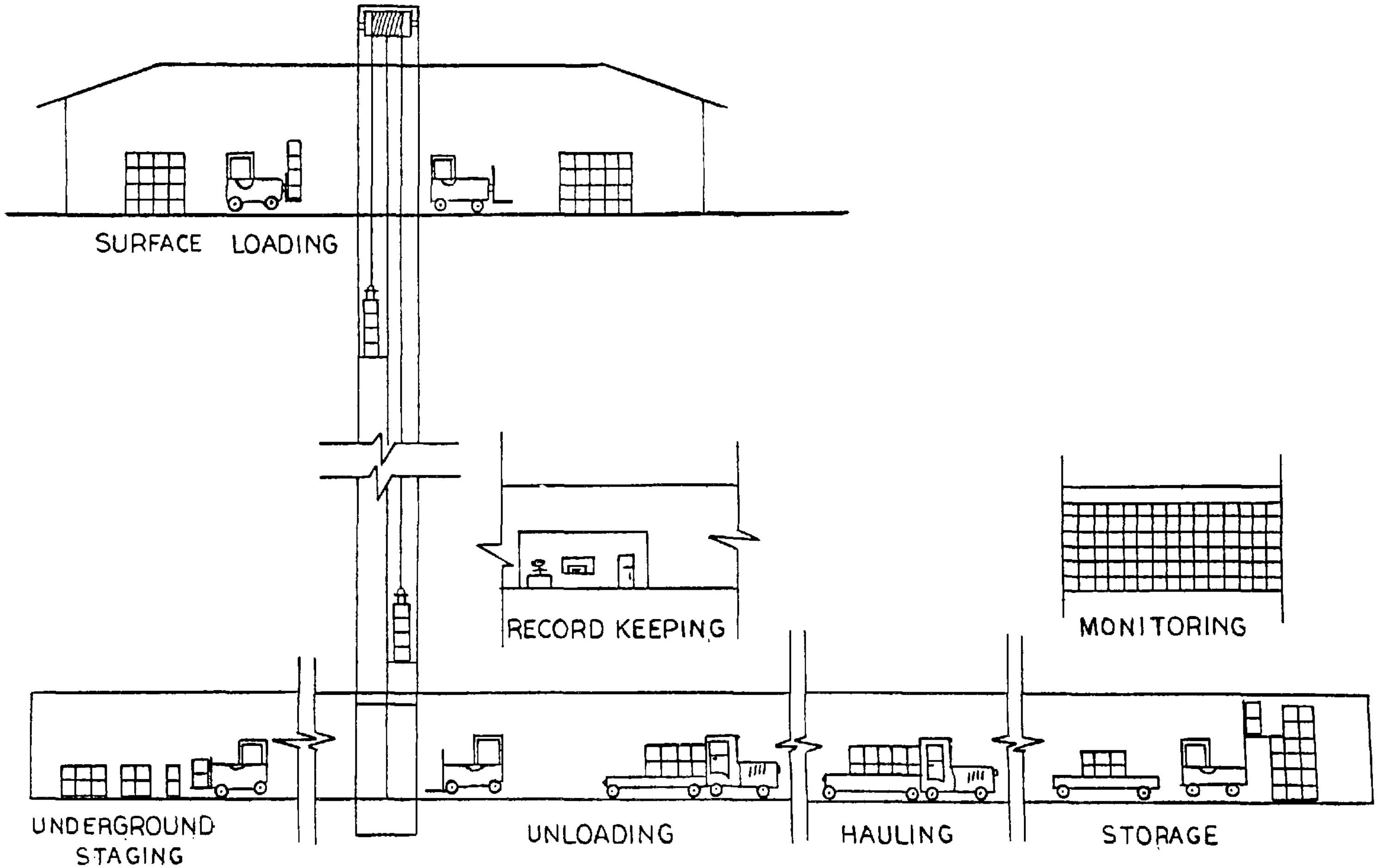


Figure 26. Schematic diagram of subsurface operation.

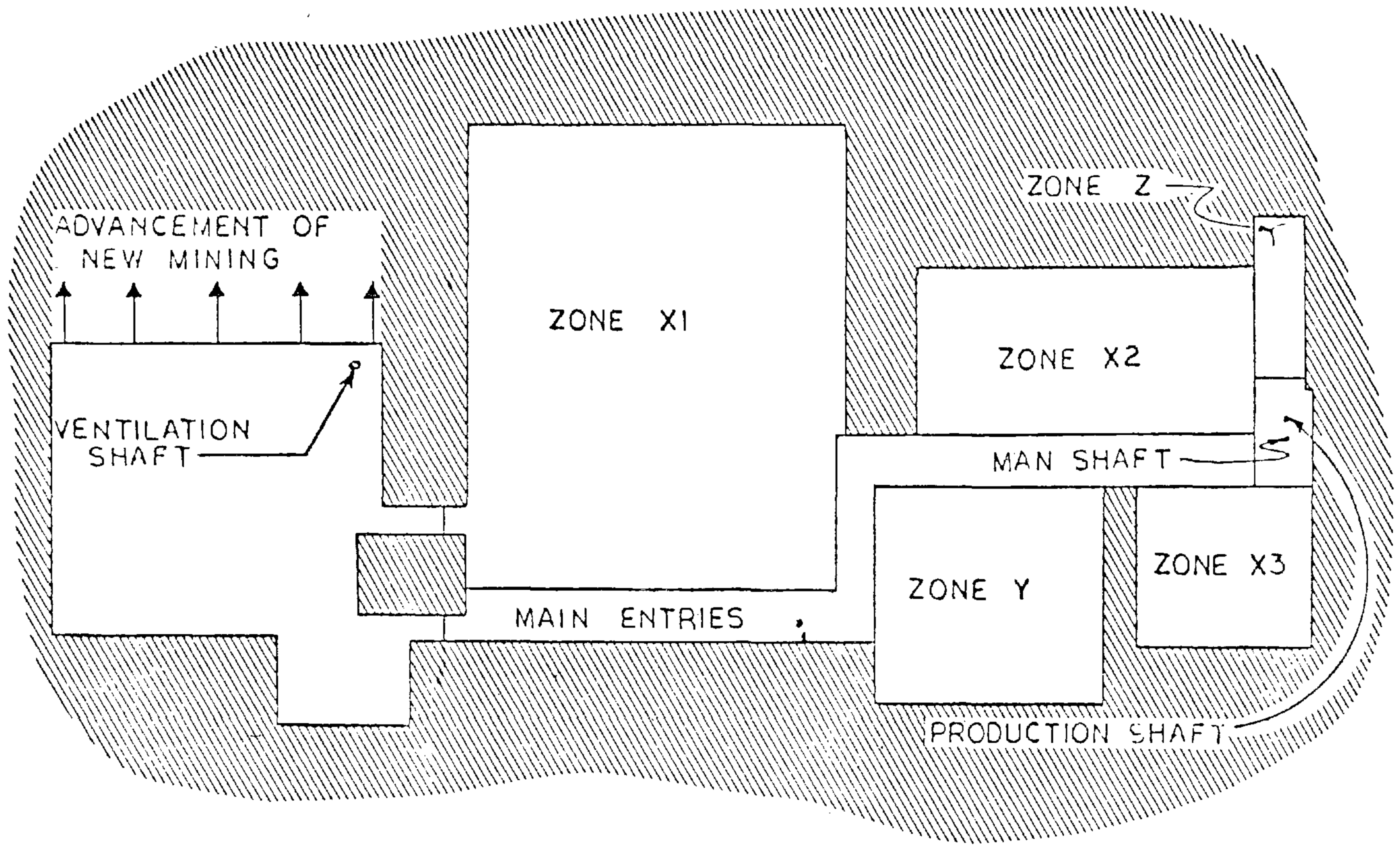


Figure 5. General mine layout.

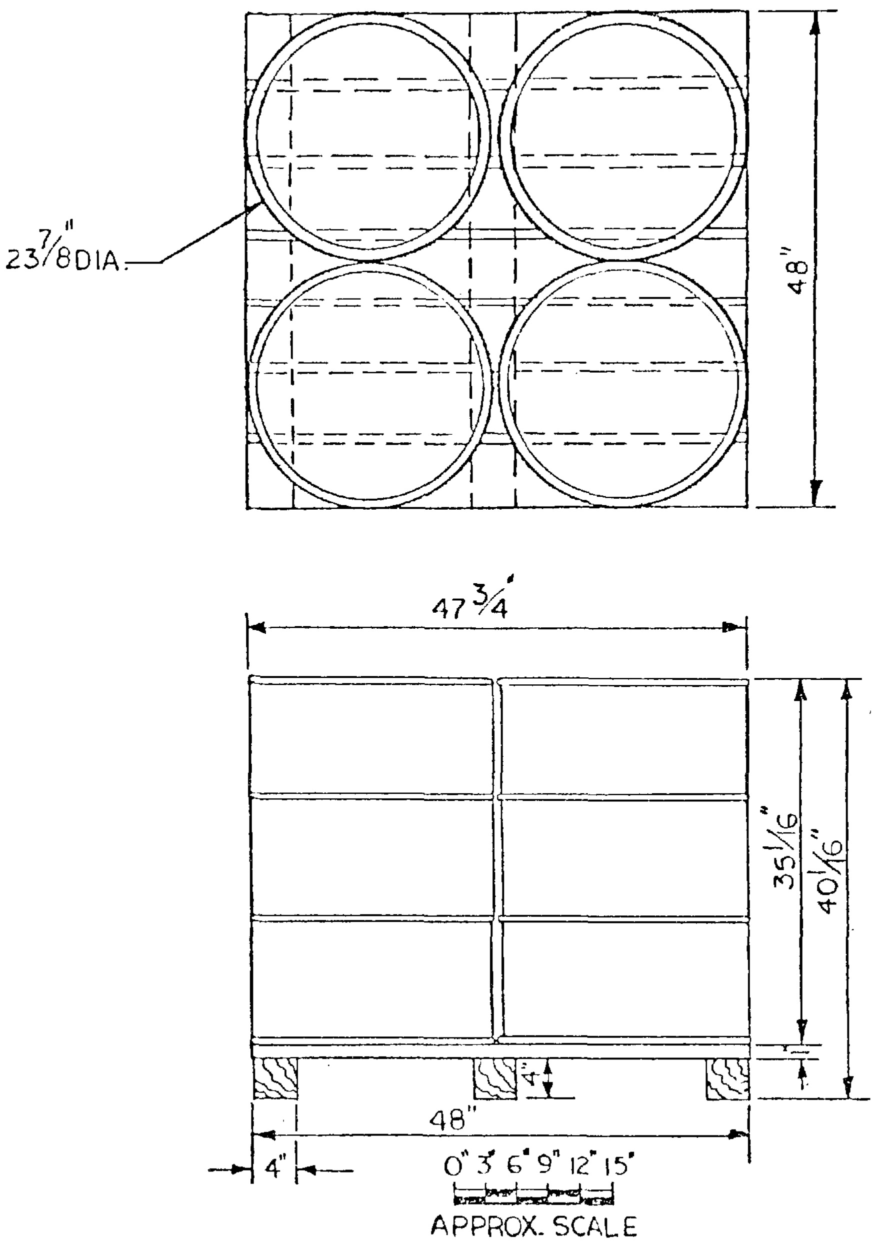


Figure 27. Drums and pallet.

The lowering operation will use a two-compartment balanced electric hoist system housed in the 16-foot-diameter production shaft. It will take 1.5 minutes to descend the 1,400 feet. As the loaded skip is being lowered in one compartment, the empty skip will be raised in the other compartment. The production shaft and hoisting system are existing facilities and will require minor rehabilitation.

Underground Unloading and Staging

The underground unloading operation (Figure 26) at the base of the shaft is essentially the reverse of the surface loading operation. A whole skip load (4 pallets) will be taken out of the skip using a forklift and set aside for another forklift to pick up two pallets at a time and load them onto a waiting flatbed haul truck.

Normally, underground staging will not be used; however, if there is any reason to stop the waste hauling to the storage area, those wastes will be temporarily stored in the underground staging area until they can be transferred to the storage area. The staging area will consist of seven rooms of approximately 40 by 40 by 22 feet in height. The wastes will be stored in two pallet stacks, and the staging area will have the capacity to hold one day's waste. The wastes in the staging area can be sent directly to the storage area or to the shaft area to load on the haul truck.

Open space for the underground staging area is already available. Minor rehabilitation work of scaling roof, roof bolting, and floor grading is required. This is discussed further in the latter part of this section and also in Appendix D.

Haulage to Storage Zone

Flat bed trailers powered by diesel tractors will be used to transfer the wastes (drums on pallets) from the shaft area to the storage zones. A normal load will consist of 20 pallets (80 drums) or 25 tons. There will be 28 shipments to storage each day or 14 shipments per shift. Round trip distances to the storage zones will vary from an average of 3,000 feet (to Zone Z) to an average of 18,000 feet (to sections of Zone X). During one shift, the wastes will be hauled to the same storage zone.

Eight flatbed trailers and three tractors will be used for hauling. One tractor and one trailer will normally be stationed at the shaft area loading the pallets. Two tractors will normally be on the road either taking loaded trailers to the storage area or bringing back the empty trailers to the shaft area. Equipment and personnel involved in this operation are listed in Appendices C and E.

Storage

The storage operation can take place in any of five storage zones (Figures 5, 28, and 29). Each storage zone is formed by many existing interconnected rooms of approximately 60 by 60 by 22 feet high. Each of these storage zones will be isolated from the others by unmined salt barriers or

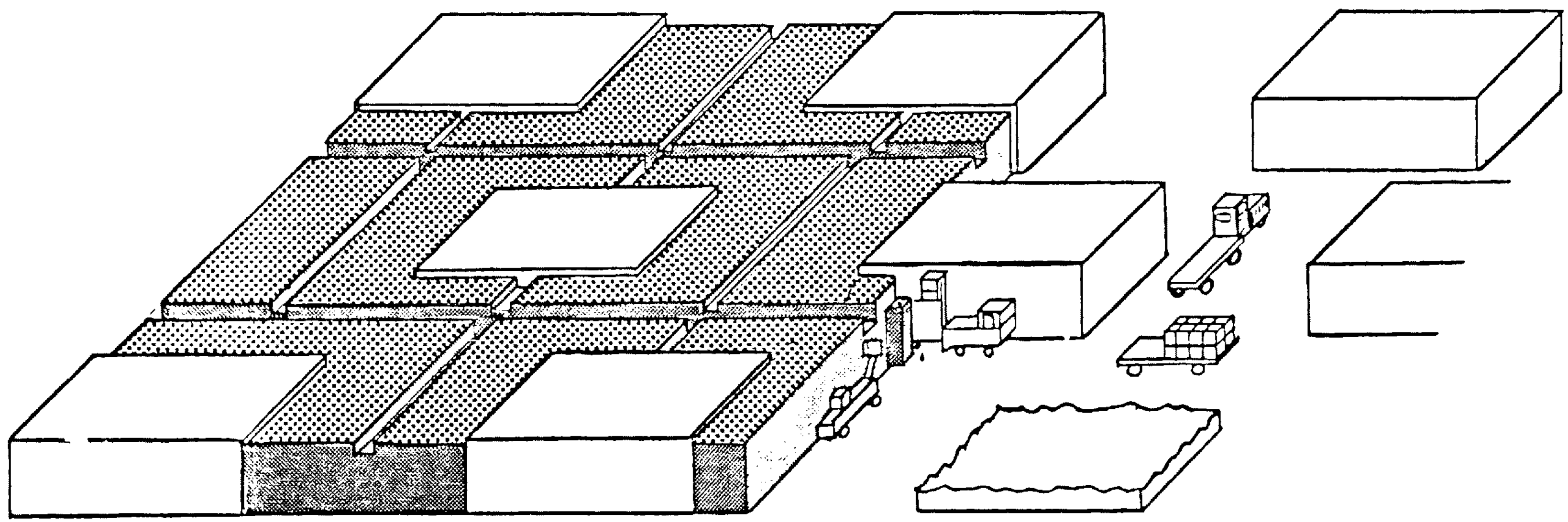


Figure 28. Schematic diagram of long-term storage operation.

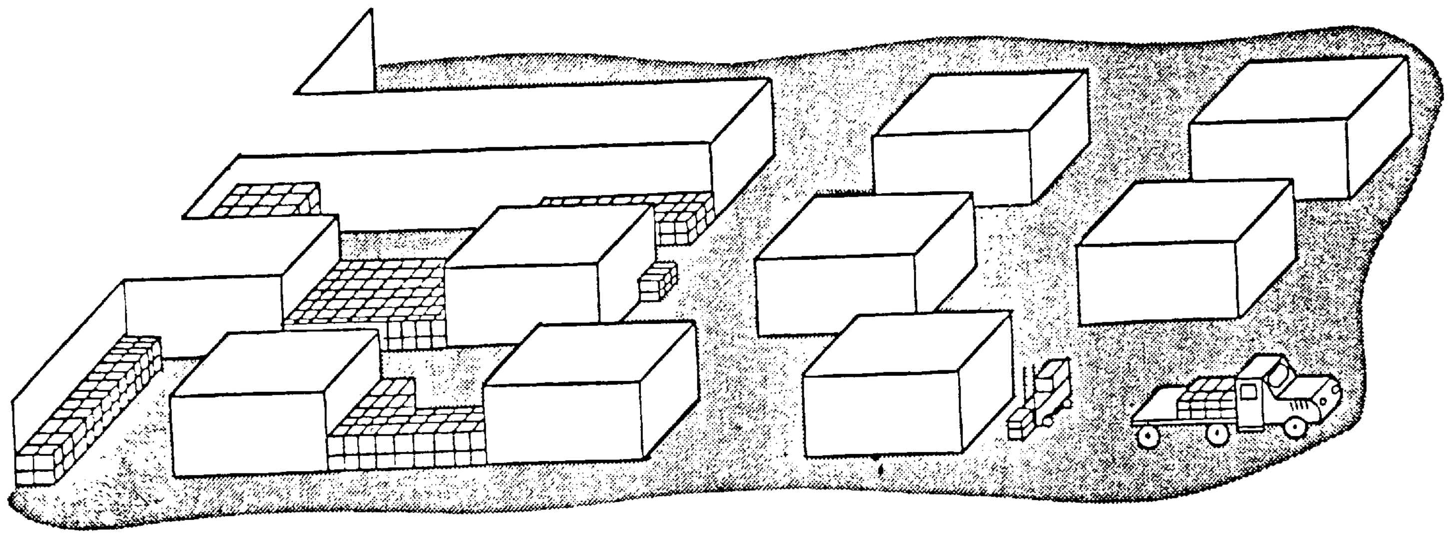


Figure 29. Schematic diagram of retrievable storage (Type D) operation.

by ventilation stopping constructed of waste salt. Storage rooms will have been prepared by scaling of ribs and roofs, roof bolting, and grading and brushing of the floor. As needed, sub-divisions will be formed within each zone by constructing waste salt barriers.

Normally, the underground operation will be scheduled in advance so that only one storage crew is necessary, and the crew will be working in the same zone during one working shift. A waste trailer will be brought into a room of the designated storage zone and parked for unloading (Figures 28 and 29). A fork lift will unload two pallets at a time from the trailer and place them in storage.

Long-Term Storage --

In long-term storage zones (X and Y), pallets will be stacked six pallets high (Figure 28) and locked together for additional stability.

In an average long-term storage cell (60 by 60 by 22 feet), there will be room to hold 1,350 pallets. Some of this capacity cannot be utilized because of space provided for side clearance and monitoring access (Figure 28). Allowing a 10 percent loss would permit storage of 1,218 pallets (4,872 drums or 1,523 tons) per room. This would require an average stacking of 14 pallets by 14½ pallets by six pallets per room. On this basis, a room would be filled every 2.25 days. During one year's operation, 125 rooms would be utilized for long-term storage, 105 rooms allocated for Zone X and 20 for Zone Y. The average storage density under these conditions would be 38.5 pounds per cubic foot, 43 percent of the room space. Actual usage of the total available space will be considerably less than this, because of haulageway,storage of waste salts, airways, and underground facilities.

The long-term storage operation is not designed to allow selective retrieval of the stored waste. Although waste that has been recently emplaced may be easily retrieved, this will not be possible for most stored waste. Retrieval from Zones X and Y would involve massive rehandling of material and in most cases would disrupt the normal storage operations. It is anticipated that total retrieval of the stored waste would require at least the same amount of time required for emplacement, if not more.

Temporary Storage --

In the temporary, short-term storage area, Zone Z, it is assumed that an average of 300 tons or 240 pallets per week are stored for a period of two years. After an initial buildup of material (24,000 pallets), the amount of waste material sent to storage will be offset by a similar amount of material removed from storage. Waste pallets may be stored in 1, 2, 3, or 4 pallet stacks. To facilitate retrieval, rooms will not be filled to capacity (Figure 29).

Retrieval of Type D waste in Zone Z would be scheduled on a one-shift-per-week basis and would be conducted concurrently with shipments to Zone Z. The retrieval process will be the reverse of the emplacement procedure. At the shaft unloading area and the surface loading area, the backup forklift trucks would be utilized to assist in the retrieval. After a skip load of waste has been unloaded at the shaft bottom, a load of retrieved waste will be placed on the skip for hoisting. In normal operations, retrieval will be conducted by the regular storage crew and no additional personnel would be required. If necessary, the room preparation crew could assist in the retrieval operation. Retrieved wastes will be sent to the drum storage building and then loaded to either a truck or box car to ship to the owner.

Storage Cell Preparation

Preparation of the storage cell will be one of the major underground activities. A typical room used for storage will be approximately 60 by 60 by 22 feet in height. Prior to use for storage, these rooms will be cleaned of waste salt and debris, will have the roof and ribs scaled and be roof bolted, and will have the floor graded and brushed (Figure 30). Preparation will be done on a continuous basis, maintaining a one-month supply (12 rooms) of prepared rooms in Zones X and Y.

Waste salt produced during salt mining and stored in the rooms must be removed. For this study, it was assumed that 5 percent of the storage volume was filled with waste salt. This is taken to be 150 tons of waste salt per room. Most waste salt will be hauled to an unused portion of the mine space. Some of it will be used to build ventilation stoppings within the storage facility. After the room is emptied, the roof and ribs will be scaled of loose rock and the roof is roof bolted. This will be done on four-foot centers using 10-foot bolts, requiring 225 bolts per room. The final step in room preparation will be to prepare a level floor for the stacking of waste pallets. In most cases this will be accomplished by spreading waste salt on the floor, spraying with water and rolling. Where this is not satisfactory, grading or brushing may be used.

Monitoring

With the exception of Type D wastes (50 TPD), all wastes will be converted to solid form and should not generate toxic, flammable, or hazardous spills. However, there is a remote possibility that a broken drum may release some waste that becomes airborne and enters circulating air systems.

The minimum requirement of a detection, monitoring, and control system will include:

- Continuous monitoring of circulating air for particulates
- Continuous monitoring of storage Zone Z for free fluid
- A system for any employee to report any spill, odor, or any unusual sight at the instance of finding and to get immediate attention of a proper inspector
- The capability for analyzing all possible contaminants in air and water
- Decontamination capability on surface and subsurface area

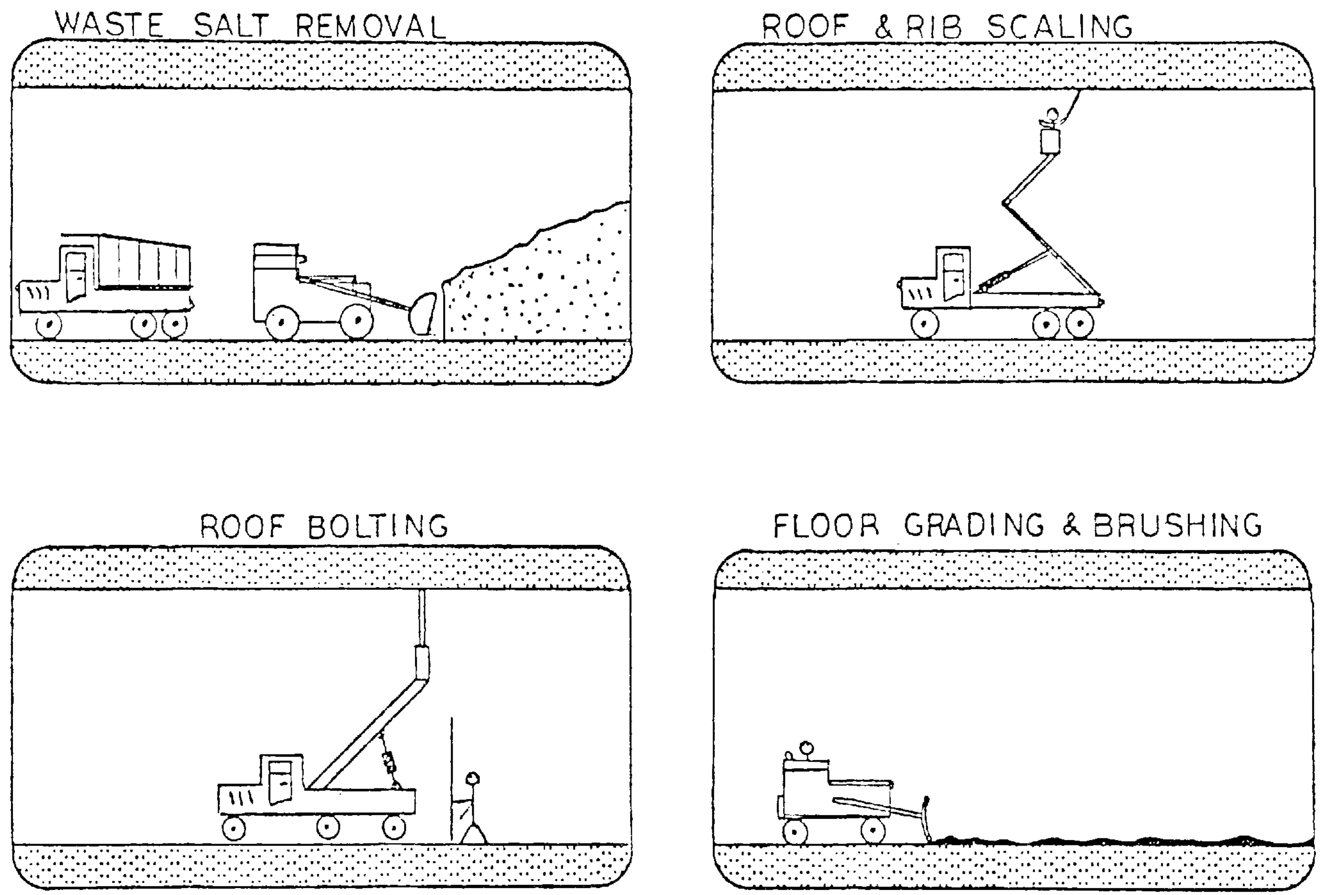


Figure 30. Schematic diagram of storage cell preparation cycle.

A standard laboratory will be provided on the surface area. In addition to usual laboratory equipment, the laboratory will be provided with a gas chromatograph, atomic absorption spectrophotometer, and organic carbon analyzer.

In addition to monitoring for possible contaminants, structural integrity of the mine space has to be monitored. This will be conducted by semi-annual reading of convergence gauges and dilation pins. A series of convergence gauges and dilation pins had been installed during the mining operations as part of a monitoring program. These instruments will continue to be monitored as part of the storage operation. Access to these monitors is provided by omitting some waste pallets to provide manways as shown in Figure 28. Additional instruments will be added as needed.

Record Keeping

The record keeping operation requires that records be maintained of all stored drums, including type of waste, date of receiving, and storage location. Each drum will be coded for its waste type and date of receiving and storage. The storage crew supervisor will be responsible for recording the location of these drums and maintaining the record file in both surface and subsurface offices.

Underground Facilities

Major underground facilities will include shafts, ventilation systems, underground staging area, haulways, storage cells, and service buildings. These facilities are discussed below. Rehabilitation work specification and their costs are summarized in Appendix D.

Shafts --

Three shafts will be used in the storage plant. Two shafts, the production and the man shaft, exist, located in the vicinity of the surface facilities. The third shaft will be a new ventilation shaft located in the mining area. Fresh air will be taken in through the ventilation shaft and exhausted through the production shaft.

The production shaft will be a circular shaft, concrete lined, and 16 feet in diameter. The shaft will be divided into two 5 by 6-foot hoisting compartments and two service compartments. A two-skip balanced electric hoist will be used for production. The 4 by 8 foot man shaft contains two 3½ by 3½ foot compartments. A two-cage balanced electric hoist will be used. The third shaft will be an 8 foot diameter concrete lined ventilation shaft. It will be equipped with an emergency personnel hoist but is otherwise without fittings.

The ventilation shaft will be a new shaft 8 feet in diameter and 1,400 feet deep. Minor rehabilitation will be required for the production shaft and the man shaft. This includes grouting some sections of both shafts and rehabilitating shaft walls and shaft timbers. These works and their costs are summarized in Appendix D.

Ventilation System --

The ventilation system will operate in conjunction with that of the active salt mining facility. Fresh air will be drawn into the mine by a 5-foot-diameter fan located at the base of the new ventilation shaft and exhausted at the production and main shafts (Figures 5 and 31). In this system, the main entries will provide fresh air for the haulage ways, the underground service area, the underground staging area, and the various storage zones. All activity will take place in air that has not passed through the storage zones. To prevent mixing of storage air with fresh air, a series of ventilation drifts have been established in a salt bed 100 feet above the storage cells. These drifts connect with the production shaft. Ventilation raises (36 in. diameter) located in each of the storage areas connect the two levels. Booster fans located at the top of each raise exhaust the air from the storage zones. A main backup fan is located in the underground service.

Underground Staging Area --

The underground staging area is intended to provide temporary storage for one day's production. The staging area, which will be located adjacent to the production shaft (Figure 32), will consist of seven storage cells. Each cell will be approximately 40 by 40 by 22 feet in height. All cells will be roof bolted with 10-foot bolts on 4-foot centers.

Haulways --

Waste hauling will, as much as possible, be confined to designated haulways (Figure 4), approximately 60 feet wide and 22 feet high. The primary haulway is presently existing. The haulway will be separated from the rest of the operation by ventilation stoppings. These stoppings will consist of rooms filled with waste salt sealed at the top with brattice-foam caps. Doors will be provided at periodic intervals to provide access to the storage zones. Secondary haulways will be established as needed within the storage zones. These will provide access to the active storage cells and in turn become storage cells as they are no longer needed for haulage.

Underground Service Facilities --

The underground service area located at the base of the shafts (Figure 32) will contain various support activities, including office, record room, lunch room, restrooms, first aid station, stock rooms, vehicle service station, repair shop, and decontamination facilities (Figure 33). Sizes of these facilities and their costs are summarized in Appendix D.

Underground Utilities --

Underground utilities will include electric power, water, diesel fuel, and fire fighting equipment.

Electric Power--Electric power will be taken into the mine via a pipe adjacent to the man shaft. Electric lighting will be possible at all areas

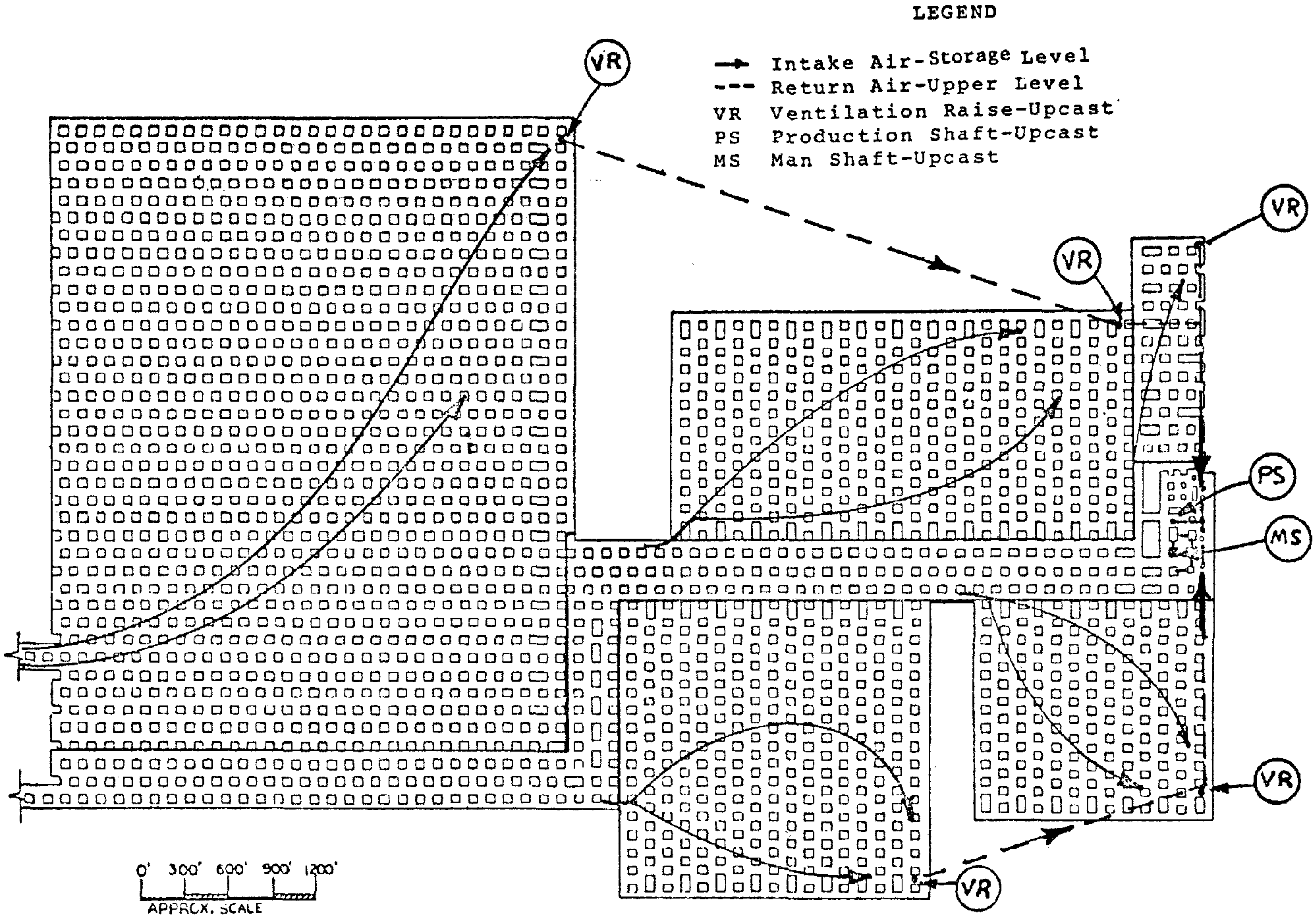
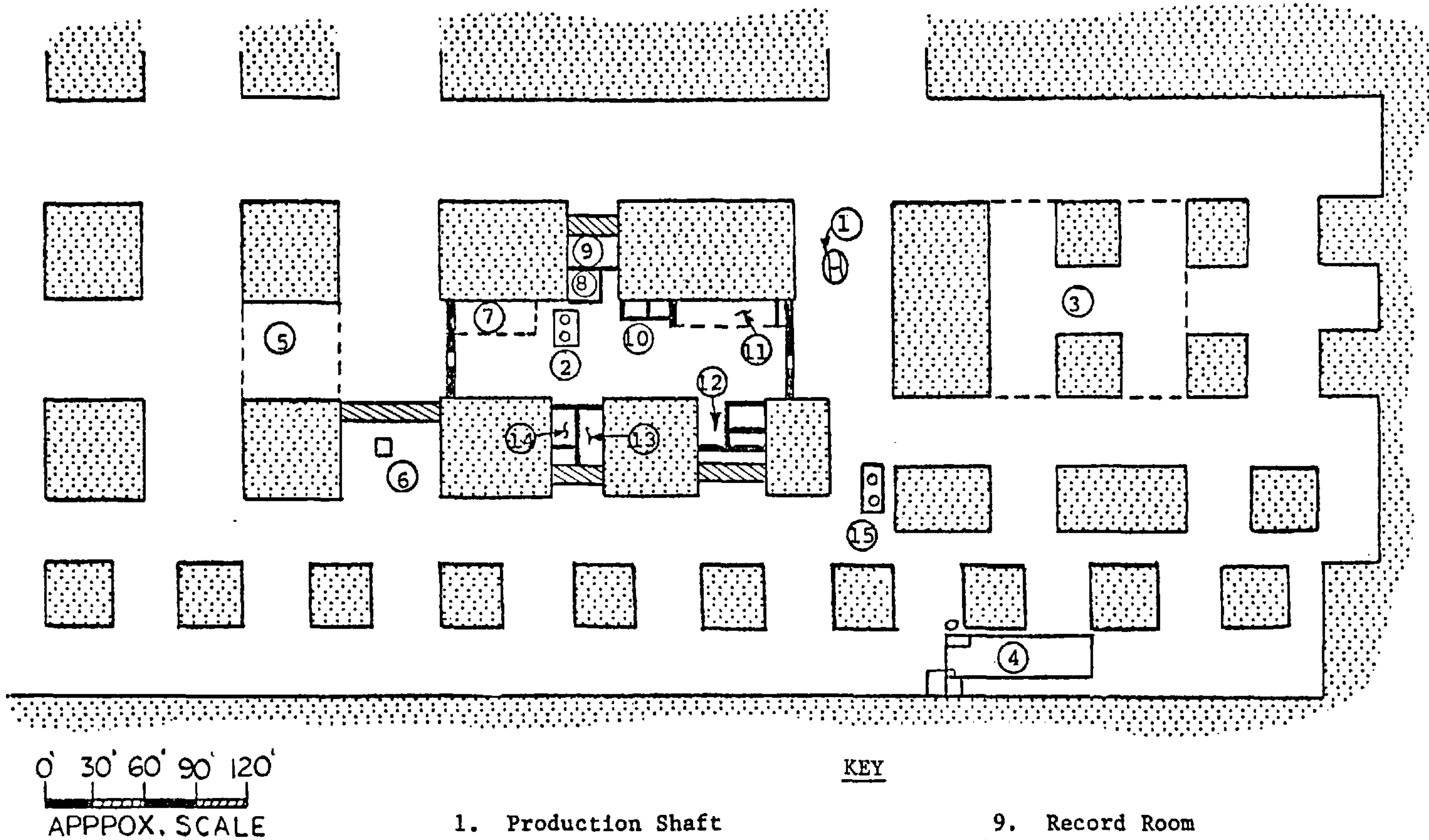


Figure 31 Subsurface ventilation plan.



KEY

1. Production Shaft
2. Man Shaft
3. Underground Staging Area
4. Decontamination Facility
5. Fire Fighting Equipment Storage
6. Ventilation Access
7. Vehicle Service Area
8. Office
9. Record Room
10. Rest Rooms
11. Maintenance & Repair Shop
12. Stock Room
13. Lunch Room
14. First Aid Station
15. Water Storage

Figure 32. Plot plan of underground service facilities.

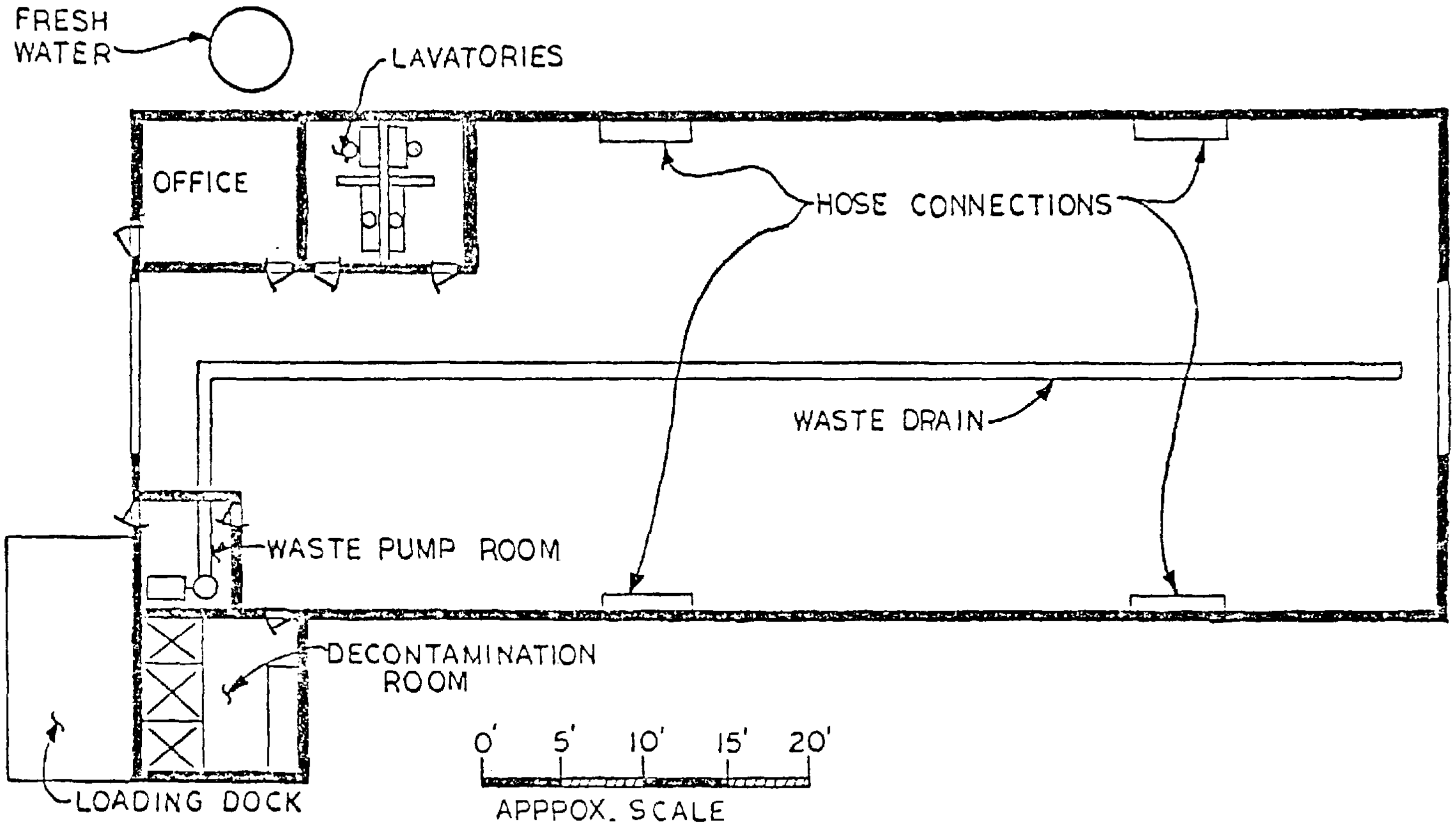


Figure 33. Underground decontamination facility.

of the storage operation, including the service area, the haulways, and the storage zones. Two separate power lines are available to the plant, and should both lines fail, emergency mobile generator will be supplied by the local power company.

Water--Decontamination water will be piped underground under natural head. The water line will extend down the production shaft service compartment and be piped to the decontamination facility, where it will supply a 20,000 gallon holding tank. Mine water will be collected in a separate 20,000 gallon holding tank, where it can be pumped to the surface by a 75 gpm single-lift pump. Contaminated water will not be handled by these facilities. All water used in decontamination operations will be placed in 55-gallon drums at the decontamination facility and hoisted to the surface for processing.

Diesel Fuel--Diesel fuel will be piped underground under natural head. The fuel line will extend down a drill hole to the mine level and then to a 500-gallon storage tank.

Fire Fighting Equipment--Fire fighting equipment will be housed adjacent to the underground service area. There is limited potential for fires in the underground operations, due primarily to the lack of combustibles underground. Fire will be controlled by standard non-water techniques such as CO_2 and fire suppressing foam.

ALTERNATIVE STORAGE CONCEPTS

Five alternative cases are included in this study. These include three different plant capacities of the same waste composition, an alternative waste composition, and a non-container storage concept. In summary, these alternative cases are:

- Case 1 (Base Case): 1,250 TPD of Type A, B, C, and D waste are received, treated, dewatered, and containerized. Six hundred and eighty-five TPD of containerized waste is stored in underground storage cells.
- Case 2 (High-Capacity Case): The same waste composition as that in the base case. The plant capacity is one and a half times that of the capacity of the base case. Handling of the waste is the same as in the base case.
- Case 3 (Low-Capacity Case): The same waste composition and handling as those in the base case. The plant capacity is 188 TPD waste received and 103 TPD stored.
- Case 4: Only Type B and C wastes (600 TPD) are received. The quantities and handling of Type B and C wastes are the same as those in the base case. Because of the absence of Type A waste, many of the surface facilities in the base case will be eliminated.
- Case 5: As in Case 4, only Type B and C wastes (600 TPD) are received. These wastes are treated, dewatered, and mixed with a cementizing additive to form a solid mass when it is placed and cured in the underground storage area.

Facilities for these alternative cases and their general design criteria are discussed below.

Case 2, High-Capacity Case

In Case 2, 1,875 TPD of Type A, B, C, and D wastes would be received and processed to store 1,030 TPD of containerized wastes. The surface and subsurface facilities would be primarily the same as those of the base case, except sizes (and numbers) of equipment and facilities would be increased to handle the increased waste loadings. Assumptions and changes in design criteria from those of the base case are:

- Two-shift operation of surface facilities and three-shift operation of subsurface facilities are assumed.
- Receiving and unloading facilities would be the same as those of the base case, except more forklifts would be needed.
- Sizes of surface buildings would be increased by 27 percent, except that the drum storage building would be increased by 50 percent.
- Mine rehabilitation and underground service buildings would be the same as those of the base case.
- Capacities of all storage tanks and bins would be increased by 50 percent, by enlargement and additional tankages.
- Capacities of all process equipment (reactor vessels and filters) would be increased by 50 percent.
- Effluent treatment capacity would be increased by 50 percent.
- The containerization system would be the same as that of the base case.
- Chemical storage capacities would be increased by 50 percent.
- All underground facilities would be the same as the base case, except for more drum handling equipment.

Case 3, Low-Capacity Case

In Case 3, 188 TPD of Type A, B, C, and D wastes would be received and processed to store 103 TPD of containerized wastes. Waste treatment, containerization, and storage methods would be the same as those of the base case. Because of the low capacity, some of the buildings and civil structures would be combined to include more than one activity, allowing changes in the plant layout and in the method of handling the wastes at various process stages. Assumptions and changes in the design cirteria from those of the base case are:

- All facilities would be operated one shift.
- Surface process building sizes would be 33 percent of the base case, except that the containerization building would be 50 percent of that in the base case.
- Shops, warehouse, and drum cleaning buildings would be combined into one and sized for 50 percent of

those in the base case.

- Administration, safety/medical, and laboratory buildings would be combined into one and sized for 50 percent of those in the base case.
- Wastes, chemicals, and empty drums would be brought to the plant by trucks.
- Approximately 50 percent of the base case plot areas would be used.
- Capacities of all tanks and bins would be 15 percent of those in the base case.
- Capacities of transport systems (pumps and conveyors) would be 33 percent of those in the base case.
- Capacities of process equipment (reactor vessels and filters) would be 33 percent of those in the base case.
- Mine rehabilitation would be the same as that of the base case, except haulways and ventilation systems are reduced.
- Effluent treatment capacity would be 33 percent of that in the base case. Only one evaporation-crystallization system would be needed.
- Containerization capacity would be 33 percent of that in the base case.
- Underground drum handling equipments would be 33 percent of those in the base case.

Case 4

Only Type B and C wastes (residue-type wastes) would be received for underground storage. Treatment and containerization of Type B and C wastes would be the same as those in the base case. Civil structures, buildings, and equipment associated with Type A and D wastes in the base case would be eliminated. Assumptions and changes in the design criteria from those of the base case are:

- All facilities would be operated two shifts, except waste receiving and unloading facilities, which would be operated for one shift.
- Wastes would be brought to the plant by trucks and railcars.
- Waste receiving and unloading facilities would be the same as those of the base case, except that drum unloading capacity would be reduced to half of that in the base case.
- Equipment and facilities involved with Type B and C wastes would be the same as those in the base case. Equipment and facilities involved with Type A and D wastes would be eliminated.
- Containerization and staging capacities would be 67 percent of those in the base case.
- Effluent treatment capacity would be 33 percent of that in the base case.
- Surface service facilities would be reduced to 50 percent of those in the base case.

- Mine rehabilitation, underground service facilities, and underground equipment would be the same as those in the base case, except that the number of the initial storage cells required are reduced proportionately.

Case 5, Non-Container Storage Case

As in Case 4, only Type B and C wastes would be received. Treatment of Type B waste, namely neutralization of acidic/caustic sludges and sludge dewatering would be the same as that in the base case. However, instead of containerizing these wastes in drums, the dewatered wastes would be mixed with a stabilizing additive (cementizing reagent) and pumped into the mine and to the storage area where the mixture would be cured to form a solid mass.

Surface facilities for receiving and unloading Type B and C wastes and their treatment and dewatering would be the same as those of Case 4. The containerization and surface staging facilities would be eliminated. The concept of non-container storage is shown in Figure 34.

Presently, three waste stabilization processes are commercially available in the country. These include Synearth process (calcilox process) of Dravo Lime Company, Chemfix process of Carborundom Company, and IUCS process of I U Conversion System, Inc. All of these stabilization methods have been known to solidify certain waste sludges such as power plant flue gas scrubber sludge and some industrial waste residues. Technical data on these processes are scarce and generally limited to leachability tests of the solidified products.

Additional work is required to confirm or disprove the technical feasibility of stabilizing (cementizing) hazardous wastes, which would allow storage of the waste without the containerization. However, available information strongly suggests that with proper preparation, this hazardous waste residue could be solidified satisfactorily. Selection of the proper additive, the mixture composition, and the emplacement method would have to be based on many more studies with waste materials and different additives. Considerably more data on solidification mechanisms of different sludges and different additives, their solidification rates, and the properties of cured mixtures are required before such a facility can be designed. For this study, the Synearth process (calcilox process) was selected for the conceptual design and approximate cost estimation. Selection of the Synearth process was not intended to imply that the process has a technical or economical advantage over the other processes. The stabilization system shown in this study is of a preliminary nature and involves assumptions on design criteria that would have to be verified by extensive research and development efforts before actual application. These assumptions include:

- Waste salts and cured materials could be used to construct three-foot dikes to contain the mixture during the curing period.
- The mixture would be pumpable.
- The mixture would not have free flowing water, and it can be cured directly on the salt bed.

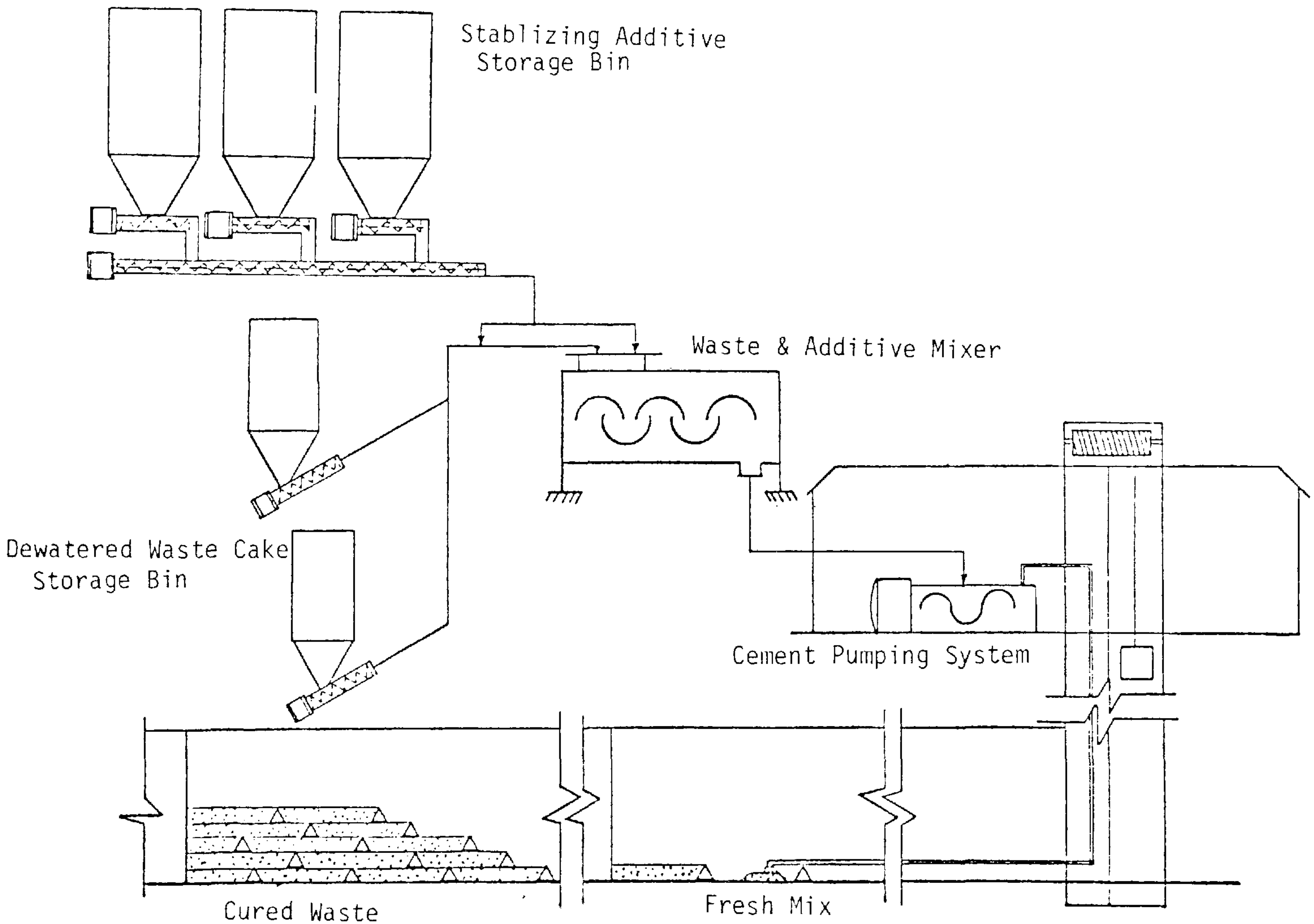


Figure 34. Schematic diagram of stabilized waste storage operation.

- The mixture would not emit any toxic vapor or gaseous product that could harm the operating personnel and public.
- The cured mixture would support earth moving equipment used in the mine.

Four hundred TPD of Type B waste would be processed to produce 220 TPD of filter cake having minimum 40 percent solid contents. This would include 20 TPD solid residue resulting from evaporation of the plant wastewater. Two hundred TPD of Type C waste would be received and stored. Fifty TPD of Type C waste would be brought to the plant in drums and transferred directly into the mine and to the storage area as is. The major steps of the stabilization system include:

- Mixing of the additive and waste
- Pumping the mixture into the mine and to the storage cells
- Curing the mixture
- Preparation of the containment structures

Major equipment of the stabilization system, in addition to waste receiving and unloading, treatment and dewatering, and mine hoisting system would include:

- Additive Receiving and Storage: 32' x 10' x 8' hopper, 100 foot conveyor system, six 100 ton bins.
- Additive and Waste Mixing: Two 6-ton/hour additive feeders, two 30 ton/hour sludge feeders, two 800 cubic foot/hour ribbon mixers.
- Mixture Pumping System: 250 gpm cement pump system (dual-pump package unit), two 8-in. by 5,000-foot pipelines and fitting system, 1,000-gallon surge tank.
- Preparation of Containment Structure: A haul truck, a front-end loader, a forklift, two floor graders.

Section 5

CAPITAL AND OPERATING COST

Cost data associated with emplacement of hazardous wastes in an underground salt mine are presented in this section. The cost data include both capital and operating costs. The economic analysis, including the unit cost (cost per ton), and sensitivity analysis are presented in Section 6. The capital cost reflects the costs of:

- Land and mine
- Site development
- Buildings and civil structures
- Equipment, piping, electrical, and instrumentation
- Engineering service, contingency, and allowances during construction

The operating cost reflects the costs of:

- Direct labor and materials
- Maintenance labor and materials
- Overhead labor and materials
- Taxes and insurances, and long-term liability insurance

These costs were estimated based on the conceptual design of the waste storage plant. The method of cost estimation and summaries of the estimates are presented in this section.

The cost data were developed for the five alternative plant concepts; three plant capacities (Cases 1, 2, and 3), an alternative waste composition (Case 4), and an alternative storage method (Case 5). The costs for these alternative concepts were compared to evaluate the sensitivity of these variables. The cost data of the base case (Case 1) was also broken down to the waste types (Types A, B, C, and D), so that the cost for each waste type subject to different processes could be compared.

The most detailed cost estimation effort was made for the base case. The base case capital costs were estimated from the lists and specifications of equipment, buildings, and mine rehabilitation requirements. The lists of these items, their specifications and their costs are summarized in Appendices C and D. The base case operating costs were estimated from a detailed list of labor (Appendix E) and material requirements.

All costs presented in this report are based on first quarter 1977 prices and wages. Three versions of the same cost data are presented in this report. The most detailed cost estimates are presented in Appendices C and D. The intermediate summaries of the capital cost and the operating cost are included in this section (Tables 13, 14, and 15), and the final summaries of the total plant costs (Tables 1, 2, 3, and 4) appear in Section 2.

CAPITAL COST

The capital cost (Table 13) includes the construction cost and the cost of the mine (land, mine, and existing facilities). The construction cost includes:

- Direct field cost
- Indirect field cost
- Allowance during construction
- Engineering service cost
- Contingency

Only the direct field cost was estimated in detail based on the plant design. The other construction costs were estimated by relating them to the direct field cost based on statistical information of similar projects.

Direct Field Cost

The direct field cost was categorized into seven groups;

- Equipment
- Site development, buildings, and civil structures
- Plant utilities
- Piping, electrical, and instrumentation
- Mine rehabilitation
- New mine facility ventilation system

A detailed breakdown of each category is included in Appendices C and D. For each item, the installed unit cost was estimated. The cost information was obtained from informal vendor contacts as well as extrapolation of published data and Bechtel historical information.

Some of these costs were obtained as installed unit costs, while others were estimated from the costs of equipment, estimated bulk material, construction labor, and subcontracts.

Equipment Cost --

All mechanical equipment involved in receiving and unloading of the wastes, surface transfer, and, storage, treatment, containerization, transport into the mine and storage cells, and final emplacement of the wastes are included in this category.

The cost of equipment was estimated from the conceptual design presented in Section 4. Lists of equipment, specifications, and costs are summarized

TABLE 13. CAPITAL COST ESTIMATE OF FIVE ALTERNATIVE CASES

Item	Base Case Case 1	Case 2	Case 3	Case 4	Case 5
	$1000's	$1000's	$1000's	$1000's	$1000's
WASTE QUANTITY					
Received Waste, Tons/Year	375,000	562,500	56,250	180,000	180,000
Stored Waste, Tons/Year	205,500	309,000	30,900	126,000	126,000
EXISTING MINE:					
Land & Existing Facility *	30,000	30,000	30,000	30,000	30,000
NEW SURFACE FACILITY:					
SITE DEVELOPMENT & BUILDINGS					
Site Preparation & Grading	360	406	130	234	234
Receiving & Unloading Buildings	610	717	203	494	382
Waste Storage Buildings	750	1,085	150	375	375
Process Buildings	2,996	4,014	1,140	1,877	1,156
Plant Wastewater Treatment Buildings	180	229	119	119	119
Service Buildings	1,430	1,824	710	944	944
	6,326	8,275	2,452	4,043	3,210
PLANT UTILITY	560	714	370	370	370
PROCESS MECHANICAL EQUIPMENT					
Receiving & Unloading Equipment	1,225	1,270	454	972	972
Storage & Treatment Equipment	4,808	6,852	2,592	1,786	2,023
Containerization Equipment	1,945	2,092	973	1,484	96
Plant Wastewater Treatment Equipment	4,250	5,021	1,845	1,845	1,845
Laboratory & Monitoring Equipment	200	200	200	200	200
	12,428	15,435	6,064	6,287	5,136
PROCESS PIPING, ELECTRICAL & INSTRUMENTATION					
Piping @ 30% of Mechanical Equipment	3,728	4,630	1,819	1,886	1,541
Electrical @ 25% of Mechanical Equipment	3,107	3,859	1,516	1,572	1,284
Instrumentation @ 15% of Mechanical Equipment	1,864	2,314	910	943	770
	8,699	11,083	4,245	4,401	3,595
DIRECT FIELD COST, SURFACE FACILITY	28,013	35,905	13,131	15,101	12,311
NEW SUBSURFACE FACILITY:					
MINE REHABILITATION					
Production Shaft Rehabilitation	1,250	1,250	1,250	1,250	1,250
Loading & Unloading Station	36	36	36	36	36
Man Shaft Rehabilitation	256	256	256	256	256
Underground Staging	52	52	32	52	32
Haulway Rehabilitation	63	63	17	63	17
Storage Cell Preparation	92	137	23	60	23
	1,749	1,794	1,614	1,717	1,614

continued

TABLE 13. (Continued)

Item	Base Case Case 1	Case 2	Case 3	Case 4	Case 5
	$1000's	$1000's	$1000's	$1000's	$1000's
VENTILATION SYSTEM					
New Ventilation Shaft	2,750	2,750	2,750	2,750	2,750
Ventilation System - Airways & Equipment	1,687	1,687	8	1,687	1,687
	4,437	4,437	2,758	4,437	4,437
UNDERGROUND SERVICE BUILDINGS	231	231	111	231	231
UNDERGROUND EQUIPMENT					
Loading, Hoisting & Unloading Equipment	351	351	188	351	158
Hauling Equipment	183	236	110	183	54
Storage Equipment	1,031	1,495	764	1,031	1,325
Ventilation Equipment	82	82	47	82	82
Miscellaneous Underground Equipment	165	190	99	165	159
	1,812	2,354	1,208	1,812	1,778
DIRECT FIELD COST, SUBSURFACE FACILITY	8.229	8,816	5,691	8,197	8,060
TOTAL DIRECT FIELD COST	36,242	44,721	18,822	23,298	20,371
TOTAL INDIRECT FIELD COST					
@ 80% of Construction Labor (6% of Total Direct Field Cost)	2,175	2,684	1,129	1,398	1,222
TOTAL FIELD COST	38,417	47,405	19,951	24,696	21,593
ALLOWANCE DURING CONSTRUCTION					
@ 1% of TFC + $500,000	884	974	699	747	716
ENGINEERING SERVICE					
@ 15% of TFC	5,763	7,111	2,993	3,704	3,239
CONTINGENCY					
@ 25% of TFC	9,604	11,851	4,988	6,174	5,398
TOTAL CONSTRUCTION COST	54,668	67,341	28,631	35,321	30,946
WORKING CAPITAL @ 10% of TCC	5,467	6,734	2,803	3,532	3,095
TOTAL INVESTMENT	90,135	104,075	61,494	68,853	64,041

NOTE: Number of significant figures shown in the table may exceed those justified by accuracy of the estimate.

* See page 107

in Appendix C. The cost information for these items was obtained from reports of parametric studies, potential supplier's quotes, and Bechtel cost information files. Some of the equipment costs were obtained as package system costs. These include the liquid waste incineration system, the vapor-recompression evaporation system, and the drum containerization system.

Site Preparation, Building, and Civil Structure Cost --

Site preparation includes site clearing, grading, and new railroad tracks. Buildings and civil structures include 10 receiving and unloading stations, seven service buildings, five process and waste storage buildings, and nine underground service buildings. The construction costs for these items were estimated from the required bulk material, labor, subcontract, and permanent equipment. Specification for these work items and their costs are shown in Appendix D. These costs are summarized in Table 13.

Plant Utility Cost --

The plant utilities include the steam generating boiler, cooling tower, electric power supply and lighting system, storm and sewage drainage systems, yard safety, and the compressed air system. The costs of these items, except the boiler and cooling tower, were estimated from the required bulk material, labor, subcontract, and permanent equipment. The costs of the boiler and cooling tower were obtained as package unit costs.

Piping, Electrical, and Instrumentation Cost --

All pipings, electrical works, and the instrumentation necessary for the operation of surface process equipment are included in this category. Based on historical information of similar type and size projects, the costs of piping, electrical, and instrumentation for surface facility were estimated to be 30, 25, and 15 percent of the installed equipment cost, respectively. For the subsurface facility, the costs of piping, electrical, and instrumentation were incorporated into the facility costs.

Mine Rehabilitation and New Mine Facilities Cost --

Most of the existing underground mine facilities will be reused with minor rehabilitation. These include production shaft, underground staging area, haulways, and waste storage cells. The only new mine facility required for the waste storage is the ventation system consisting of new 8- by 1,400-foot shaft, ventilation fans, and ventilation raises, drifts, and stoppings. The specifications and costs of these work items are shown in Appendix D and summarized in Table 13.

Mine Acquisition Cost --

The cost of acquiring an operating mine can be approached from several points of view. One basis for evaluation is facility replacement value. The cost of the mine could be determined by the replacement value of the existing plant, equipment, facilities, and land at today's prices. The second approach would be in terms of an opportunity cost. The value could be determined, not by the existing facilities, but by the value of alternative uses for the facility. A third approach would establish value in terms of the cost of creating a new mine to meet the needs of the storage operation.

The approach selected for use in this study was that of facility replacement value. This was considered the best approach for this study because of the availability and reliability of needed information. Actual capital costs and investment were determined and adapted to the modified mine in order to establish a facility replacement value ($30,000,000).

The opportunity cost approach was not pursued because of the lack of information relating to the purchase of mines for alternative uses. It was felt that development of this type of data was outside of the scope of the contract. The space created in salt mining has several alternative uses which render the space potentially valuable. These include petroleum storage, compressed air storage for peak shaving of electric power, and warehouse space. Presently, the federal government is negotiating with several mining companies to acquire existing mines for use for strategic oil storage. One mine owner has stated the cost of its mine to be $160,000,000 (Wall Street Journal, 4/20/77). Once these negotiations have been accomplished, a suitable opportunity cost may be available and related to the current project.

The third alternative, developing new mine costs, was not pursued. This approach could perhaps be utilized in determining the cost of a combined new mine and storage facility.

In this study, $30,000,000 was set as the acquisition cost of the mine and facilities. This represents the replacement value of a mine similar to the one described in the study. Included in this evaluation are the surface land, surface plant, the mine shafts, and the underground facilities.

In the particular mine selected, the assumption was made that the mine facilities would be relocated at a distance from the hazardous waste storage facility. This would allow continuous operation of both the mine and the storage facility. In order to achieve this, however, all the mine facilities would have to be replaced. The salvage value of the existing surface and plant facilities would be minimal. The relocation of the mining activity would necessitate the development of a new mining system utilizing new equipment. The $30,000,000 acquisition value represents the cost of replacing the existing facilities and does not represent the cost of developing new facilities at a new location.

Indirect Field Cost

The indirect field costs are those construction cost items that cannot be ascribed directly to the individual construction work item. These include temporary construction facilities, miscellaneous construction services such as general cleanup, construction equipment rental, field overhead, and field insurance and taxes. Based on past projects of similar type and size, the indirect field cost was estimated as 6 percent of the total direct field cost.

Engineering Service Cost

The engineering service cost includes those costs for plant design, specification, vendor-drawing review, procurement service, estimating and scheduling services, quality assurance, and construction management. Based on Bechtel data, the engineering service cost for this type of plant was estimated to be 15 percent of the total field cost.

Allowance During Construction

The cost for obtaining various permits, environmental impact reports, and public relations and education are included in this category. Public acceptance of the project is very important. Public education must be planned in advance of the plant construction. Public relations and education will involve both state and local communities. The activities would include education on the needs of the project, the safety of the project, and the potential benefits of the project to the community and the state.

Initially, the public relations and education program will be a joint effort of the owner and a consultant in the field, but when the plant starts operating, a permanent staff will be hired to handle the program on a continuous basis. The cost items for the public relations and education program are public notification, community forums, survey by questionnaires, brochures and articles, a spokesman, and a planning staff.

Various permits from local, state, and federal governments will be required for the construction of the plant and its operation. An environmental impact report of the project will also be required. Based on Bechtel information and experience, $200,000 was estimated as the cost of the environmental impact report, and 1 percent of the total field cost was allocated for the public relations and education program and for acquiring the necessary permits before and during construction.

Contingency

The capital cost estimate for this study was based on the conceptual design of the facilities. This design contains uncertainties in the effectiveness of some of the selected processes, in quantity and size of some of the selected equipment, and in their pricing. Often in a conceptual design, a process is simplified due to the lack of detailed information, and the cost estimate based on the conceptual design may miss the cost items that only detailed design can reveal. The contingency includes the allowance for these uncertainties within the design and pricing. Based on past experience with projects of a similar type and size, the contingency for this project was estimated to be 20 percent of the total field cost.

OPERATING COST

The operating cost was estimated from the conceptual facilities design and its operating plan described in Section 4. The operating costs were divided into four categories:

- Direct Labor and Materials
  -- Direct operating labor
  -- Chemicals, containers, and utilities
- Maintenance Labor and Materials
  -- Maintenance labor
  -- Maintenance materials
- Plant Overhead
  -- Administrative and staff personnel
  -- General supplies
- Fixed Cost
  -- Taxes and insurance
  -- Depreciation
  -- Long-term liability insurance

The operating costs for all five alternative cases are summarized in Table 14. The base case operating cost was divided into the costs for the four waste types according to their actual process requirements. The allocation of the base case operating cost to the four waste types is shown in Table 15. The cost allocation to the four waste types compares relative operating costs of the different wastes received at the plant. The cost allocation does not imply that a waste storage plant receiving only a part of the base case waste can operate at the corresponding cost. The operating cost per ton shown in Tables 14 and 15 does not include the cost of capital (interest charge on the capital). The unit cost (cost per ton), which includes the cost of capital, is presented in Section 6.

All plant personnel, except administrative and staff personnel, were assumed to be union members. Their annual salaries are based on hourly wages and 2,400 working hours per year plus 8 percent for overtime compensation and 30 percent for the payroll additive. The labor costs used in this study were based on the actual union labor costs of the selected mine. All materials and utility costs are the costs of those delivered to the selected mine site.

<u>Direct Labor and Materials</u>

Direct Labor Cost --

For every step of the waste pathway shown in the material flow charts (Figures 8 through 12), operating manpower requirements, including numbers and types of personnel, were estimated. In general, operating personnel are classified into labor (utilityman), operator (equipment operator), and foreman (supervisor). The detailed labor requirement and costs are shown in Appendix E. The summary of the labor cost for all five cases is shown in Table 14.

Chemicals, Containers, and Utility Costs --

Chemical usage is based on the waste composition and the treatment requirement shown in Tables 7 and 9, respectively. Stabilization additive will be used only in Case 5 and its usage is discussed in Section 4. Unit costs of these chemicals (cost per ton) delivered to the plant site and their annual costs are shown in Tables 14 and 15.

Container costs were based on $22 per drum (55-gallon, open top, epoxy-lined, 16 gauge steel drum) delivered to the plant site. Drum usage is based on 625 pounds of the waste per drum. Heavy duty pallets will be delivered to the plant at $6 each. Their usage is based on one pallet for four drums.

Based on the approximate horsepower (3,500 HP for the base case) of involved equipment and their usage, the total electric power requirement was estimated. Similarly, usages of diesel fuel (1,770,000 gallons per year) and gasoline (20,000 gallons per year) were estimated. Potable water usage (3,000,000 gallons per year) was estimated at 35 gallons per person per day. All utility costs were based on current prices at the selected mine site.

Maintenance Labor and Material Cost

Maintenance labor for the five alternative cases was estimated in the same manner as that for the direct operating personnel. Categories, numbers in each category, and their annual costs are shown in Appendix E. Total maintenance labor costs are shown in Tables 14 and 15.

Maintenance materials include equipment replacement and maintenance, and repair supplies, including lubricating oils, replacement parts, and other supplies used in conjunction with repair work. Maintenance material costs were approximated by relating them to the total equipment costs. Due to difficulty of determining service life of the equipment, higher than normal equipment maintenance cost was used as an alternative to the maintenance material plus the investment in the replacement facility. The cost of maintenance materials for the surface equipment including replacement facility were approximated to be 15 percent of the total surface equipment cost, while the maintenance material cost for the underground equipment was approximated to be 20 percent of the total underground equipment cost.

Plant Overhead

The plant overhead includes the cost of administrative and staff personnel and the cost of general supplies. Numbers and types of administrative and staff personnel required for the base case operation were estimated on the assumption that the waste storage plant is a combination of a chemical manufacturing plant and a salt mine. Composition of the administrative and staff personnel and their costs are shown in Appendix E. Total administrative and staff personnel costs are shown in Tables 14 and 15.

General supplies include office supplies, medical supplies, laboratory supplies, and other supplies used in normal operation of the plant, excepting the direct materials and maintenance materials. The cost of general supplies was approximated to be 5 percent of the total labor cost.

Fixed Cost

The fixed cost includes property taxes and insurance, depreciation, and

TABLE 14. OPERATING COST ESTIMATE OF FIVE ALTERNATIVE CASES

Item	Base Case Case 1	Case 2	Case 3	Case 4	Case 5
	$1000's	$1000's	$1000's	$1000's	$1000's
WASTE QUANTITY					
Received Waste, Tons/Yr	375,000	562,500	56,250	180,000	180,000
Stored Waste, Tons/Yr	205,500	309,000	30,900	126,000	126,000
DIRECT MATERIALS & LABOR					
RAW MATERIALS & UTILITIES					
SURFACE OPERATION:					
CHEMICALS					
Sulfur Dioxide (liquid, $185/Ton)	133.2	199.8	20.0	0	0
Chlorine (liquid, $210/Ton)	571.2	856.8	85.7	0	0
Lime (90%, $55/Ton)	330.0	495.0	49.5	42.9	42.9
Caustic Soda (50% sol., $105/Ton)	456.8	685.2	68.5	0	0
Ferric Chloride (35% sol., $52.5/Ton)	23.6	35.5	3.6	11.8	11.8
Sulfuric Acid (78% sol.. $54/Ton)	10.8	24.3	2.4	0	0
Stabilization Additive ($45/Ton)	0	0	0	0	220.0
	1,525.6	2,296.6	229.7	54.7	274.7
DRUMS & PALLETS:					
Drums (55 gallon epoxy lined, $22 ea.)	12,540	18,810	1,881	7,700	0
Pallets ($6 each)	855	1,283	128	525	0
	13,395	20,093	2,009	8,225	0
UTILITIES:					
Power ($0.04/KW-HR)	760	1,120	152	320	360
Fuel Oil ($0.37/gallon)	655	951	100	163	163
Gasoline ($0.60/gallon)	12	16	3	6	6
Water & Sewer Service ($1.0/$10^3$ gallon)	3	4	.8	1.6	1.6
	1,430	2,091	255.8	490.6	530.6
SUBSURFACE OPERATION					
UTILITIES:					
Power ($0.04/KW-HR)	272.4	328	56	272	192
Diesel Oil ($0.37/gallon)	203.4	304	40	160	50
Water & Sewer Service ($1.0/$10^3$ gallon)	8	1.2	.3	.7	.7
	476.6	633.2	96.3	432.7	242.7
	16,827.2	25,113.8	2,590.8	9,203.0	1,048.0
DIRECT LABOR					
SURFACE OPERATION:					
Waste Receiving & Unloading	639.1	913.4	260.9	382.6	382.6
Waste Treatment	498.3	593.3	148.3	221.0	375.1
Containerization & Staging	1,048.3	1,260.7	311.0	766.1	0
Plant Wastewater Treatment	369.4	369.4	175.0	175.0	175.0
	2,555.0	3,136.8	895.2	1,544.7	932.7
SUBSURFACE OPERATION:					
Loading, Hoisting & Unloading	388.8	583.2	144.0	288.0	144.0
Hauling	169.2	253.8	46.1	169.2	46.1
Storage	160.6	240.8	93.6	160.6	72.7
Storage Cell Preparation	421.2	645.1	144.0	370.8	97.9
Stabilization (Case 5 only)					365.0
	1,139.8	1,722.9	427.7	988.6	725.7
TOTAL DIRECT LABOR	3,694.8	4,859.7	1,322.9	2,533.3	1,658.4

continued

TABLE 14. (continued)

Item	Base Case Case 1 $1000's	Case 2 $1000's	Case 3 $1000's	Case 4 $1000's	Case 5 $1000's
MAINTENANCE					
LABOR					
SURFACE OPERATION:	685.9	841.9	318.2	526.1	526.1
SUBSURFACE OPERATION:	879.1	1,065.6	159.8	852.5	388.1
	1,565.0	1,907.5	478.0	1,378.6	914.2
MATERIAL					
SURFACE OPERATION (@ 15% of Surface Equipment)	3,253	4,145	1,602	1,659	1,365
SUBSURFACE OPERATION (@ 20% of Underground Equipment)	390	471	241	362	356
	3,643	4,616	1,843	2,021	1,721
	5,208	6,523.5	2,321	3,399.6	2,635.2
OVERHEAD					
ADMINISTRATIVE & STAFF PERSONNEL					
SURFACE OPERATION:	1,288.3	1,592.0	485.0	828.0	583.0
SUBSURFACE OPERATION:	197.7	296.6	49.4	197.8	152.2
	1,486.0	1,888.6	534.4	1,025.8	735.2
GENERAL SUPPLIES					
SURFACE OPERATION: (@ 5% of Labor)	226	279	85	145	102
SUBSURFACE OPERATION (@ 5% of Labor)	111	154	32	102	63
	337	433	117	247	165
	1,823	2,321.6	651.4	1,272.8	900.2
FIXED COST					
TAXES AND INSURANCE(3)					
@ 2% of Plant Cost and $1.10 per ton for Long Term Liability Insurance	2,215	2,700	1,292	1,575	1,479
OPERATING COST (4)	29,769	41,520	8,178	17,984	7,720
Cost Per Ton Received(4), $/Ton	79.3	74	145	100	43
Cost Per Ton Stored(4), $/Ton	144.7	134	265	143	61

NOTE: (1) Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

(2) Labor costs include 30% payroll additive and 8% overtime compensation.

(3) Insurance includes $1.10 per ton (0.5¢/gallon) of received waste for Long Term Liability and other insurances.

(4) Cost of Capital and depreciation is not included.

TABLE 15. OPERATING COST ESTIMATE OF BASE CASE AND ITS ALLOCATION TO TYPES A, B, C, AND D WASTES

Item	BASE CASE (CASE 1)				
	Total $1000's	Type A $1000's	Type B $1000's	Type C $1000's	Type D $1000's
WASTE QUANTITY:					
Received Waste, Tons/Yr	375,000	180,000	120,000	60,000	15,000
Stored Waste, Tons/Yr	205,500	64,500	66,000	60,000	15,000
DIRECT MATERIALS & LABOR					
RAW MATERIALS & UTILITIES					
SURFACE OPERATION					
CHEMICALS:					
Sulfur Dioxide, (liquid, $185/ton)	133.2	133.2	0	0	0
Chlorine, (liquid, $210/ton)	571.2	571.2	0	0	0
Lime, (90%, $55/ton	330.0	287.1	42.9	0	0
Caustic Soda, (50% sol., $105/ton)	456.8	456.8	0	0	0
Ferric Chloride, (35% sol., $52.5/ton)	23.6	11.8	11.8	0	0
Sulfuric Acid, (78% sol., $54/ton)	10.8	10.8	0	0	0
Stabilization Additive, ($45/ton)	0	0	0	0	0
	1,525.6	1,470.9	54.7	0	0
DRUMS & PALLETS:					
Drums, (55 gallon, epoxy lined, $22 each)	12,540	4,620	4,708	3,212	0
Pallets, ($6 each)	855	314	322	219	0
	13,395	4,934	5,032	3,431	0
UTILITIES:					
Power, ($0.04/KWH)	760	508	216	28	8
Fuel Oil, ($0.37/gallon)	655	492	163	0	0
Gasoline, ($0.60/gallon)	12	5.8	3.8	1.9	.5
Water & Sewer Service ($1.0/10^3 gallon)	3	1.4	1.0	.4	.2
	1,430	1,007.2	383.8	30.3	8.7
SUBSURFACE OPERATION:					
UTILITIES:					
Power, ($0.04/KWH)	272.4	79.7	81.5	74.1	37.1
Diesel Oil, ($0.37/gallon)	203.4	59.5	60.9	55.3	27.7
Water & Sewer Service, ($1.0/10^3 gallon)	.8	.2	.3	.2	.1
	476.6	139.4	142.7	129.6	64.9
	16,827.2	7,551.5	5,611.2	3,590.9	73.6
DIRECT LABOR (2)					
SURFACE OPERATION:					
Waste Receiving & Unloading	639.1	261.6	223.2	91.6	62.7
Waste Treatment	498.2	303.8	194.4	0	0
Containerization & Staging	1,048.3	359.4	359.4	291.0	38.5
Plant Wastewater Treatment	369.4	240.1	99.7	22.2	7.4
	2,555.0	1,164.9	876.7	404.8	108.6
SUBSURFACE OPERATION:					
Loading, Hoisting & Unloading	388.8	113.7	116.4	105.8	52.9
Hauling	169.1	49.5	50.6	46.0	23.0
Storage	160.7	47.0	48.1	43.7	21.9
Storage Cell Preparation	421.2	123.2	126.1	114.6	57.3
Stabilization (Case 5 Only)	0	0	0	0	0
	1,139.8	333.4	341.2	310.1	155.1
TOTAL DIRECT LABOR	3,694.8	1,498.3	1,217.9	714.9	263.7

continued

TABLE 15 (continued)

Item	BASE CASE (CASE 1)				
	Total $1000's	Type A $1000's	Type B $1000's	Type C $1000's	Type D $1000's
MAINTENANCE					
LABOR					
SURFACE OPERATION:	686.0	316.6	211.0	105.6	52.8
SUBSURFACE OPERATION:	879.0	257.1	263.1	239.2	119.7
	1,565.0	573.7	474.1	344.8	172.4
MATERIAL					
SURFACE OPERATION: (15% of Surface Equipment)	3,253	1,745	1,074	396	38
SUBSURFACE OPERATION: (20% of Und. Equip.)	390	114	117	106	53
	3,643	1,859	1,191	502	91
	5,208	2,432.7	1,665.1	846.8	263.4
OVERHEAD					
ADMINISTRATIVE & STAFF PERSONNEL					
SURFACE OPERATION:	1,288.3	594.6	396.4	198.3	99.0
SUBSURFACE OPERATION:	197.7	57.8	59.2	53.8	26.9
	1,486.0	652.4	455.6	252.1	125.9
GENERAL SUPPLIES					
SURFACE OPERATION:	226	104	70	35	17
SUBSURFACE OPERATION:	111	33	33	30	15
	337	137	103	65	32
	1,823	789.4	558.6	317.1	157.9
FIXED COST					
TAXES & INSURANCE (3)					
(@ 2% of plant cost and $1.10 per ton for Long Term Liability Insurance)	2,215	933	696	428	158
OPERATING COST (4)	29,769	13,205	9,749	5,898	917
Cost Per Ton Received (4), $/Ton	79.4	73.4	81.2	98.3	61.1
Cost Per Ton Stored (4), $/Ton	144.9	204.7	147.7	98.3	61.1

NOTE: (1) Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

(2) Labor rate includes 30% payroll additive (fringe benefits) and 8% overtime compensation.

(3) Insurance includes $1.10 per ton (0.5¢/gallon) of received waste for Long Term Liability and other insurance.

(4) Cost of capital and depreciation is not included.

long-term liability insurance.

Property Taxes and Insurance --

Property taxes and plant insurance were approximated to be 2 percent of the plant cost. This includes property taxes paid to city, school district, and state, and property insurances against loss or disablement due to fire, flood, and explosion. The long-term liability insurance is handled separately and discussed below.

Depreciation --

The simple straight line depreciation method was used to compute the cost of plant depreciation; that is, annual depreciation is equal to the total depreciation value divided by the plant service life. The plant service life is determined based on presently available mine space and waste storage rates. The maximum plant service life was assumed to be 40 years. The plant service lives for Cases 1, 2, 3, 4, and 5 are 30, 20, 40, 40 and 40 years, respectively, In actual operation, all cases may have much longer service life because concurrent salt mining activity can produce more new mined space than that used by the waste storage.

The depreciable value is the total plant cost minus the salvageable value at the end of the plant service life. The land and some portion of the surface facilities and equipment will be salvageable at the end of the plant service life. However, at the end of service, the facility will have to be decommissioned. This may include removing some of the surface facilities, construction of physical barriers in the mine to prevent potential water intrusion, and plugging up all shaft holes. It is impossible to estimate the salvageable value or the decommissioning cost with any accuracy at the present time. For simplicity, it was assumed that all salvageable values will be used in decommissioning the plant at the end of its service life. This will result in depreciating plant cost over the plant life.

Long-Term Liability Insurance --

The problems of perpetual or long-term care and liability of hazardous waste management facilities are of vital concern to the public. Some of the considerations related to implementing long-term care and liability provisions are:

- Operation of plant by reliable owner
- Final closing and subsequent perpetual monitoring and maintenance of the storage facility
- Financial capability of the owner in the assessment of possible liability

With respect to the perpetual monitoring and maintenance after the mine is filled to capacity, it was assumed that the underground facility will be permanently decommissioned including construction of impermeable barriers and sealing the shaft openings so that monitoring and maintenance will not be required. The cost for the decommissioning will be paid out of the salvage value. Accordingly, it is not anticipated that a combined surety bond and perpetual care fee will be required.

With respect to the liability insurance problem, it was assumed that the owner will have liability insurance against a hazardous waste pollution incident in addition to the standard public liability protection. Currently, numerous unresolved questions concerning financial liability, insurability, government indemnification, and standards must be resolved before a universally acceptable methodology can be developed to determine an appropriate premium for such liability insurance. For this study, it was assumed that long-term liability insurance for the hazardous waste storage operation will be $1.10 per ton of received waste (0.5¢ per gallon). This assumption is based on the experience of one hazardous waste service firm that paid approximately $10,000 or less than $0.01 per gallon for an average of $500,000 bodily injury, $500,000 personal, and $3 million for property damage for each occurrence (Ref. 31).

COMPARISON OF SELECTED MINE WITH OTHER MINES

The mine selected for this study is located in a bedded salt deposit. The operation of the hazardous waste storage facility described in this report could also apply to other bedded salt deposits. The primary differences would be in terms of the surface facilities, the depth of the deposit below the surface, the thickness of the seams, the size of the room openings, and the amount of void space available for storage. The actual operation of the storage facility would be relatively unchanged, regardless of which bedded salt deposit was selected for use as a storage facility as long as it satisfied the specific criteria discussed in Section 3.

In the study case, all of the surface facilities for the waste storage operation will be new, except the production shaft and approximately one half of the railroad tracks. The existing surface facilities of the selected mine are typical of presently operating room and pillar type salt mines. Because the surface operation of the waste storage plant is more a chemical process activity than a mining activity, the requirement for completely new surface facilities for the waste storage plant is likely to be common for other mines of the same type. Depending on available land, railroad, and highways, the layout of the surface facilities may change to some extent if other mines are selected; however, the cost differences due to the different layouts should be minimal when compared to the overall surface facility cost.

The particular mine selected for the study will continue mining in a distant section of the mine. Because of the coexistence of the waste storage and salt mining, $2,750,000 has been included for the development of a new ventilation shaft. This ventilation shaft could serve both the mine and the hazardous waste storage facility. If mining operations were not to continue, this item could be eliminated.

Several items are included in the cost estimation of the selected mine that are unique to this facility. Similar cost items may be necessary for other mines, and these are identified here for comparative purposes.

Grouting of the two existing shafts would be required because of the condition of the overlying beds. Many other bedded salt deposits would require similar grouting. There are, however, some operations in which this would not be necessary. The dollar figures (production shaft grouting -- $1,000,000; and service shaft grouting -- $225,000) are costs for the selected mine and would not necessarily be the same for other operations. They would vary depending upon the depth to the grout zone and the specific problems associated with the water inflow.

Storage cell preparation will involve the removal of waste salt from the proposed storage cells. Many salt mines store waste salt underground in the abandoned mine workings. The amount of salt and the difficulty in removing it will vary from mine to mine. This will be reflected in both the capital costs in terms of initial cell preparation and in the annual operating cost, since salt will be removed on a continual basis during the life of the operation. The disposal of waste salt may add significantly to the underground operating costs.

In the selected mine, roof bolting is proposed throughout the storage area. This is an added safety precaution. The majority of the mine has a stable roof and has not presented any problem during mining. The degree of roof support required will vary from mine to mine and will again be reflected in the capital cost and the operating cost. It is expected, however, that most bedded salt deposit mines would utilize roof bolting as an added precaution.

The ventilation system used in the selected mine will involve a two-level system. Fresh air will be taken in a new ventilation shaft located in the area of the current mining activity. This air will be split, one portion going to the mining operation, and the other portion going to the hazardous waste storage facility. Air that enters each of the storage zones at the mine level will be removed through ventilation raises to a level 100 feet above the storage operation. This air will then be removed to the production shaft, where it will be exhausted to the surface. This system will require the development of a substantial amount of ventilation drifts as well as six ventilation raises. The cost of this system was approximately $1,662,000 and was necessitated by the mine plan. It was not possible to route air that was passed through the storage cells to the exhaust shaft without passing through areas in which men would be working. The mine plan of other mines will vary and this particular type of system may not be necessary.

In comparison with other mines of bedded salt, the capital costs presented in this study can be taken as representative of the costs that would be incurred to convert an existing mine of bedded salt to a storage facility. The operating costs for different mines would be similar. The specific differences that might occur are the cost of the ventilation shaft, the cost of grouting the existing shafts, and the cost of developing a new ventilation level for the mine.

The primary difference between a hazardous waste storage facility located in a bedded salt deposit and one located in a salt dome would be in the size of the underground openings. Room heights in dome salt may be as high as 150 feet. This height would pose difficult problems for the storage of waste utilizing methods proposed in this study. For this reason, a direct comparison between the cost of waste disposal in a salt dome, as opposed to a bedded salt deposit, would not be accurate. A different system would have to be developed to utilize openings of such large scale.

The costs developed in this study would be similar for other room and pillar mines, regardless of the type of the deposit. Assuming that the deposit met the necessary requirements for isolation from water and stability, the cost differences would be primarily a function of the specific site and less dependent on the characteristics of the mined resource. If, for example, a suitable limestone mine was located, the cost of the storage operation would be similar to that of the study mine.

In general, then, the cost developed in this study can be taken as representative of the costs of establishing a hazardous waste storage facility in an existing mine. The costs would be valid for room and pillar mines of dimensions and depth similar to the example study. A storage facility located in a thinner seam would undoubtedly involve higher operating costs. This would be due primarily to the increased haulage distances necessary to handle the same volume of waste. The development of a storage facility in a seam or an opening of larger dimensions would also probably involve higher operating costs. This would be due primarily to the additional costs associated with stacking and stabilizing containerized waste at greater heights.

Section 6

ECONOMIC ANALYSIS

The purpose of this section is to present the results of an economic analysis of five hazardous waste storage alternatives (Cases 1 through 5) for which capital investment and operating cost are presented in Section 5. The objective of the analysis is to estimate the unit cost, cost per ton (as received) to receive, treat, containerize (all but Case 5), and store the hazardous waste. The sensitivity of the unit cost to some of the plant variables is also determined.

The unit costs were estimated using the discounted cash flow net present value methodology. For each of the five cases, the unit costs were estimated for two different plant ownership possibilities, namely private versus public:

1. The hazardous waste facility is privately owned, has a 10 percent return on investment, 100% equity, and pays 48 percent income tax.

2. The hazardous waste facility is government owned, has 6 percent cost of capital, and pays no income tax.

Also assumed for the economic analysis were the following:

- The plant will have a 300 stream-day operating year.
- The plant will process only 60 percent of its designed capacity in the first year; accordingly, only 60 percent of the chemicals, drums and pallets, utilities, and plant maintenance budget will be utilized in the first year.

A summary of the economic analysis of the five cases is presented in Table 16. As shown in the table, the unit cost for each case is presented for both the privately owned facility and for the government owned facility. All unit costs shown in Table 16 are the waste management fee based per ton of received waste, not per ton of stored waste. Tables 17 through 26 present the *pro forma* discounted cash flow analysis for the privately owned facility (Tables 17 through 21) and for the government owned facility (Tables 22 through 26).

To ascertain the relative importance of the size of the storage plant, the return on investment, and the cost of the mine on the estimated unit costs, sensitivity analyses were performed on the base case unit cost as a function on these parameters. It is important to emphasize that the analysis utilized order-of-magnitude cost estimates, and, therefore, the unit costs

TABLE 16. SUMMARY OF WASTE MANAGEMENT FEE
(UNIT COST PER TON, 1977 DOLLARS)

	Case 1	Case 2	Case 3	Case 4	Case 5
Capital Cost ($ 1,000's)	90,135	104,075	61,494	68,853	64,041
Tons Received per Year	375,000	562,500	56,100	180,000	180,000
Economic Life (years)	30	20	40	40	40
Waste Management Fee in Dollars per Ton Received					
• Privately Owned with 10% Return on Inventment	130.65	116.69	376.71	176.06	118.15
• Government Owned with 6% Cost of Capital	101.40	94.94	232.77	131.02	71.16

TABLE 17. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 1, PRIVATELY OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 1 (375000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	30	TOTAL
RETURN ON INVESTMENT 10.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	24668.0	30000.0	0.	0.	0.	0.	0.	0.	0.	54668.0
TOTAL INVESTMENT	54668.0	30000.0	0.	0.	0.	0.	0.	0.	0.	84668.0
WORKING CAPITAL	0.	5467.0	0.	0.	0.	0.	0.	0.	0.	5467.0
NET CAPITAL INVESTMENT	54668.0	35467.0	0.	0.	0.	0.	0.	0.	0.	90135.0
REVENUE:										
WASTE MANAGEMENT FEE ($130.65 PER TON)	0.	0.	16608.7	48993.9	48993.9	48993.9	48993.9	48993.9	48993.9	1437432.2
TOTAL REVENUE	0.	0.	16608.7	48993.9	48993.9	48993.9	48993.9	48993.9	48993.9	1437432.2
OPERATING COSTS:										
DIRECT LABOR	0.	0.	3695.0	3695.0	3695.0	3695.0	3695.0	3695.0	3695.0	110850.0
CHEMICALS & CATALYSTS	0.	0.	915.0	1525.6	1525.6	1525.6	1525.6	1525.6	1525.6	45157.4
DRUMS & PALLETS	0.	0.	8037.0	13395.0	13395.0	13395.0	13395.0	13395.0	13395.0	396492.0
UTILITIES	0.	0.	1144.0	1906.6	1906.6	1906.6	1906.6	1906.6	1906.6	56435.4
ADMIN & GENERAL	0.	0.	1823.0	1823.0	1823.0	1823.0	1823.0	1823.0	1823.0	54690.0
PLANT MAINT	0.	0.	3125.0	5208.0	5208.0	5208.0	5208.0	5208.0	5208.0	154157.0
TAXES & INSURANCE	0.	0.	2215.0	2215.0	2215.0	2215.0	2215.0	2215.0	2215.0	66450.0
DEPRECIATION	0.	0.	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	84668.0
TOTAL OPERATING COSTS	0.	0.	23776.3	32590.5	32590.5	32590.5	32590.5	32590.5	32590.5	968899.8
NET OPERATING INCOME	0.	0.	-7167.5	16403.4	16403.4	16403.4	16403.4	16403.4	16403.4	468532.4
INCOME TAX LIABILITY (48.00%)	0.	0.	0.	4433.2	7873.7	7873.7	7873.7	7873.7	7873.7	224895.6
NET INCOME AFTER TAX	0.	0.	-7167.5	11970.2	8529.8	8529.8	8529.8	8529.8	8529.8	243636.8
PLUS: DEPRECIATION	0.	0.	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	84668.0
CASH FROM OPERATIONS	0.	0.	-4345.3	14792.5	11352.1	11352.1	11352.1	11352.1	11352.1	328304.8
NET CASH FLOW	-54668.0	-35467.0	-4345.3	14792.5	11352.1	11352.1	11352.1	11352.1	11352.1	238169.8
CUMULATIVE CASH FLOW	-54668.0	-90135.0	-94480.3	-79687.8	-68335.7	-56983.7	-45631.6	124649.3	238169.8	0.

TABLE 18. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 2, PRIVATELY OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 2 (562500 TPY)
(THOUSANDS OF DOLLARS)

	YEAR: -1	0	1	2	3	4	5	10	20	TOTAL
RETURN ON INVESTMENT 10.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	33341.0	34000.0	0.	0.	0.	0.	0.	0.	0.	67341.0
TOTAL INVESTMENT	63341.0	34000.0	0.	0.	0.	0.	0.	0.	0.	97341.0
WORKING CAPITAL	0.	6734.0	0.	0.	0.	0.	0.	0.	0.	6734.0
NET CAPITAL INVESTMENT	63341.0	40734.0	0.	0.	0.	0.	0.	0.	0.	104075.0
REVENUE:										
WASTE MANAGEMENT FEE ($116.69 PER TON).		0.	19714.8	65639.5	65639.5	65639.5	65639.5	65639.5	65639.5	1266865.1
TOTAL REVENUE	0.	0.	19714.8	65639.5	65639.5	65639.5	65639.5	65639.5	65639.5	1266865.1
OPERATING COSTS:										
DIRECT LABOR	0.	0.	4860.0	4860.0	4860.0	4860.0	4860.0	4860.0	4860.0	97200.0
CHEMICALS & CATALYSTS	0.	0.	1378.0	2297.0	2297.0	2297.0	2297.0	2297.0	2297.0	45021.0
DRUMS & PALLETS	0.	0.	12056.0	20093.0	20093.0	20093.0	20093.0	20093.0	20093.0	393823.0
UTILITIES	0.	0.	1634.0	2724.0	2724.0	2724.0	2724.0	2724.0	2724.0	53390.0
ADMIN & GENERAL	0.	0.	2320.0	2322.0	2322.0	2322.0	2322.0	2322.0	2322.0	46438.0
PLANT MAINT	0.	0.	3914.0	6524.0	6524.0	6524.0	6524.0	6524.0	6524.0	127870.0
TAXES & INSURANCE	0.	0.	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	54000.0
DEPRECIATION	0.	0.	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	97341.0
TOTAL OPERATING COSTS	0.	0.	33729.0	46387.0	46387.0	46387.0	46387.0	46387.0	46387.0	915083.0
NET OPERATING INCOME	0.	0.	-14014.2	19252.4	19252.4	19252.4	19252.4	19252.4	19252.4	351782.1
INCOME TAX LIABILITY (48.00%)	0.	0.	0.	2514.4	9241.2	9241.2	9241.2	9241.2	9241.2	168855.4
NET INCOME AFTER TAX	0.	0.	-14014.2	16738.1	10011.3	10011.3	10011.3	10011.3	10011.3	182926.7
PLUS: DEPRECIATION	0.	0.	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	97341.0
CASH FROM OPERATIONS	0.	0.	-9147.2	21605.1	14878.3	14878.3	14878.3	14878.3	14878.3	280267.7
NET CASH FLOW	-63341.0	-40734.0	-9147.2	21605.1	14878.3	14878.3	14878.3	14878.3	14878.3	176192.7
CUMULATIVE CASH FLOW	-63341.0	-104075.0	-113222.2	-91617.0	-76738.7	-61860.4	-46982.1	27409.5	176192.7	0.

TABLE 19. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 3, PRIVATELY OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 3 (56100 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
RETURN ON INVESTMENT 10.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	8631.0	20000.0	0.	0.	0.	0.	0.	0.	0.	28631.0
TOTAL INVESTMENT	38631.0	20000.0	0.	0.	0.	0.	0.	0.	0.	58631.0
WORKING CAPITAL	0.	2863.0	0.	0.	0.	0.	0.	0.	0.	2863.0
NET CAPITAL INVESTMENT	38631.0	22863.0	0.	0.	0.	0.	0.	0.	0.	61494.0
REVENUE:										
WASTE MANAGEMENT FEE ($376.71 PER TON)	0.	0.	3805.8	21133.4	21133.4	21133.4	21133.4	21133.4	21133.4	828009.6
TOTAL REVENUE	0.	0.	3805.8	21133.4	21133.4	21133.4	21133.4	21133.4	21133.4	828009.6
OPERATING COSTS:										
DIRECT LABOR	0.	0.	1323.0	1323.0	1323.0	1323.0	1323.0	1323.0	1323.0	52920.0
CHEMICALS & CATALYSTS	0.	0.	138.0	230.0	230.0	230.0	230.0	230.0	230.0	9108.0
DRUMS & PALLETS	0.	0.	1205.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	79556.0
UTILITIES	0.	0.	211.0	352.0	352.0	352.0	352.0	352.0	352.0	13939.0
ADMIN & GENERAL	0.	0.	651.0	651.0	651.0	651.0	651.0	651.0	651.0	26040.0
PLANT MAINT	0.	0.	1392.0	2321.0	2321.0	2321.0	2321.0	2321.0	2321.0	91911.0
TAXES & INSURANCE	0.	0.	1292.0	1292.0	1292.0	1292.0	1292.0	1292.0	1292.0	51680.0
DEPRECIATION	0.	0.	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	58631.0
TOTAL OPERATING COSTS	0.	0.	7677.8	9643.8	9643.8	9643.8	9643.8	9643.8	9643.8	383785.0
NET OPERATING INCOME	0.	0.	-3872.0	11489.7	11489.7	11489.7	11489.7	11489.7	11489.7	444224.5
INCOME TAX LIABILITY (48.00%)	0.	0.	0.	3656.5	5515.0	5515.0	5515.0	5515.0	5515.0	213227.8
NET INCOME AFTER TAX	0.	0.	-3872.0	7833.2	5974.6	5974.6	5974.6	5974.6	5974.6	230996.8
PLUS: DEPRECIATION	0.	0.	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	58631.0
CASH FROM OPERATIONS	0.	0.	-2406.2	9298.9	7440.4	7440.4	7440.4	7440.4	7440.4	289627.8
NET CASH FLOW	-38631.0	-22863.0	-2406.2	9298.9	7440.4	7440.4	7440.4	7440.4	7440.4	228133.8
CUMULATIVE CASH FLOW	-38631.0	-61494.0	-63900.2	-54601.3	-47160.9	-39720.5	-32280.1	79325.9	228133.8	0.

TABLE 20. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 4, PRIVATELY OWNED

HAZARDOUS WASTE MANAGEMENT STUDY — CASE 4 (180000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
RETURN ON INVESTMENT 10.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	15321.0	20000.0	0.	0.	0.	0.	0.	0.	0.	35321.0
TOTAL INVESTMENT	45321.0	20000.0	0.	0.	0.	0.	0.	0.	0.	65321.0
WORKING CAPITAL	0.	3532.0	0.	0.	0.	0.	0.	0.	0.	3532.0
NET CAPITAL INVESTMENT	45321.0	23532.0	0.	0.	0.	0.	0.	0.	0.	68853.0
REVENUE:										
WASTE MANAGEMENT FEE ($179.06 PER TON)	0.	0.	13050.1	32230.2	32230.2	32230.2	32230.2	32230.2	32230.2	1270026.2
TOTAL REVENUE	0.	0.	13050.1	32230.2	32230.2	32230.2	32230.2	32230.2	32230.2	1270026.2
OPERATING COSTS:										
DIRECT LABOR	0.	0.	2533.0	2533.0	2533.0	2533.0	2533.0	2533.0	2533.0	101320.0
CHEMICALS & CATALYSTS	0.	0.	33.0	55.0	55.0	55.0	55.0	55.0	55.0	2178.0
DRUMS & PALLETS	0.	0.	4935.0	8225.0	8225.0	8225.0	8225.0	8225.0	8225.0	325710.0
UTILITIES	0.	0.	554.0	923.0	923.0	923.0	923.0	923.0	923.0	36551.0
ADMIN & GENERAL	0.	0.	1273.0	1273.0	1273.0	1273.0	1273.0	1273.0	1273.0	50920.0
PLANT MAINT	0.	0.	2040.0	3400.0	3400.0	3400.0	3400.0	3400.0	3400.0	134640.0
TAXES & INSURANCE	0.	0.	1575.0	1575.0	1575.0	1575.0	1575.0	1575.0	1575.0	63000.0
DEPRECIATION	0.	0.	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	65321.0
TOTAL OPERATING COSTS	0.	0.	14576.0	19617.0	19617.0	19617.0	19617.0	19617.0	19617.0	779640.0
NET OPERATING INCOME	0.	0.	-1526.0	12613.1	12613.1	12613.1	12613.1	12613.1	12613.1	490336.2
INCOME TAX LIABILITY (48.00%)	0.	0.	0.	5321.8	6054.3	6054.3	6054.3	6054.3	6054.3	235385.4
NET INCOME AFTER TAX	0.	0.	-1526.0	7291.3	6558.8	6558.8	6558.8	6558.8	6558.8	255000.9
PLUS: DEPRECIATION	0.	0.	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	65321.0
CASH FROM OPERATIONS	0.	0.	107.1	8924.3	8191.9	8191.9	8191.9	8191.9	8191.9	320321.9
NET CASH FLOW	-45321.0	-23532.0	107.1	8924.3	8191.9	8191.9	8191.9	8191.9	8191.9	251468.9
CUMULATIVE CASH FLOW	-45321.0	-68853.0	-68745.9	-59821.6	-51629.8	-43437.9	-35246.1	87631.8	251468.9	0.

TABLE 21. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 5, PRIVATELY OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 5 (180000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
RETURN ON INVESTMENT 10.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	15000.0	15946.0	0.	0.	0.	0.	0.	0.	0.	30946.0
TOTAL INVESTMENT	45000.0	15946.0	0.	0.	0.	0.	0.	0.	0.	60946.0
WORKING CAPITAL	0.	3095.0	0.	0.	0.	0.	0.	0.	0.	3095.0
NET CAPITAL INVESTMENT	45000.0	19041.0	0.	0.	0.	0.	0.	0.	0.	64041.0
REVENUE:										
WASTE MANAGEMENT FEE ($118.15 PER TON)	0.	0.	4221.8	21267.6	21267.6	21267.6	21267.6	21267.6	21267.6	833658.9
TOTAL REVENUE	0.	0.	4221.8	21267.6	21267.6	21267.6	21267.6	21267.6	21267.6	833658.9
OPERATING COSTS:										
DIRECT LABOR	0.	0.	1658.0	1658.0	1658.0	1658.0	1658.0	1658.0	1658.0	66320.0
CHEMICALS & CATALYSTS	0.	0.	165.0	275.0	275.0	275.0	275.0	275.0	275.0	10890.0
DRUMS & PALLETS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UTILITIES	0.	0.	464.0	773.0	773.0	773.0	773.0	773.0	773.0	30611.0
ADMIN & GENERAL	0.	0.	900.0	900.0	900.0	900.0	900.0	900.0	900.0	36000.0
PLANT MAINT	0.	0.	1581.0	2635.0	2635.0	2635.0	2635.0	2635.0	2635.0	104346.0
TAXES & INSURANCE	0.	0.	1479.0	1479.0	1479.0	1479.0	1479.0	1479.0	1479.0	59160.0
DEPRECIATION	0.	0.	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	60946.0
TOTAL OPERATING COSTS	0.	0.	7770.7	9243.7	9243.7	9243.7	9243.7	9243.7	9243.7	368273.0
NET OPERATING INCOME	0.	0.	-3548.8	12024.0	12024.0	12024.0	12024.0	12024.0	12024.0	465385.9
INCOME TAX LIABILITY (48.00%)	0.	0.	0.	4068.1	5771.5	5771.5	5771.5	5771.5	5771.5	223385.2
NET INCOME AFTER TAX	0.	0.	-3548.8	7955.9	6252.5	6252.5	6252.5	6252.5	6252.5	242000.7
PLUS: DEPRECIATION	0.	0.	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	60946.0
CASH FROM OPERATIONS	0.	0.	-2025.2	9479.5	7776.1	7776.1	7776.1	7776.1	7776.1	302946.7
NET CASH FLOW	-45000.0	-19041.0	-2025.2	9479.5	7776.1	7776.1	7776.1	7776.1	7776.1	238905.7
CUMULATIVE CASH FLOW	-45000.0	-64041.0	-66066.2	-56586.6	-48810.5	-41034.4	-33258.3	83383.4	238905.7	0.

TABLE 22. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 1, GOVERNMENT OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 1 (375000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	30	TOTAL
COST OF CAPITAL 6.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	24668.0	30000.0	0.	0.	0.	0.	0.	0.	0.	54668.0
TOTAL INVESTMENT	54668.0	30000.0	0.	0.	0.	0.	0.	0.	0.	84668.0
WORKING CAPITAL	0.	5467.0	0.	0.	0.	0.	0.	0.	0.	5467.0
NET CAPITAL INVESTMENT	54668.0	35467.0	0.	0.	0.	0.	0.	0.	0.	90135.0
REVENUE:										
WASTE MANAGEMENT FEE ($101.40 PER TON)	0.	0.	7764.6	38025.1	38025.1	38025.1	38025.1	38025.1	38025.1	1110492.4
TOTAL REVENUE	0.	0.	7764.6	38025.1	38025.1	38025.1	38025.1	38025.1	38025.1	1110492.4
OPERATING COSTS:										
DIRECT LABOR	0.	0.	3695.0	3695.0	3695.0	3695.0	3695.0	3695.0	3695.0	110850.0
CHEMICALS & CATALYSTS	0.	0.	915.0	1525.6	1525.6	1525.6	1525.6	1525.6	1525.6	45157.4
DRUMS & PALLETS	0.	0.	8037.0	13395.0	13395.0	13395.0	13395.0	13395.0	13395.0	396492.0
UTILITIES	0.	0.	1144.0	1906.6	1906.6	1906.6	1906.6	1906.6	1906.6	56435.4
ADMIN & GENERAL	0.	0.	1823.0	1823.0	1823.0	1823.0	1823.0	1823.0	1823.0	54690.0
PLANT MAINT	0.	0.	3125.0	5208.0	5208.0	5208.0	5208.0	5208.0	5208.0	154157.0
TAXES & INSURANCE	0.	0.	2215.0	2215.0	2215.0	2215.0	2215.0	2215.0	2215.0	66450.0
DEPRECIATION	0.	0.	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	84668.0
TOTAL OPERATING COSTS	0.	0.	23776.3	32590.5	32590.5	32590.5	32590.5	32590.5	32590.5	968899.8
NET OPERATING INCOME	0.	0.	-16011.6	5434.6	5434.6	5434.6	5434.6	5434.6	5434.6	141592.6
INCOME TAX LIABILITY (0.00%)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NET INCOME AFTER TAX	0.	0.	-16011.6	5434.6	5434.6	5434.6	5434.6	5434.6	5434.6	141592.6
PLUS: DEPRECIATION	0.	0.	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	2822.3	84668.0
CASH FROM OPERATIONS	0.	0.	-13189.4	8256.9	8256.9	8256.9	8256.9	8256.9	8256.9	226260.6
NET CASH FLOW	-54668.0	-35467.0	-13189.4	8256.9	8256.9	8256.9	8256.9	8256.9	8256.9	136125.6
CUMULATIVE CASH FLOW	-54668.0	-90135.0	-103324.4	-95067.5	-86810.6	-78553.7	-70296.8	53556.6	136125.6	0.

TABLE 23. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 2, GOVERNMENT OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 2 (562500 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	10	20	TOTAL
COST OF CAPITAL 6.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	33341.0	34000.0	0.	0.	0.	0.	0.	0.	0.	67341.0
TOTAL INVESTMENT	63341.0	34000.0	0.	0.	0.	0.	0.	0.	0.	97341.0
WORKING CAPITAL	0.	6734.0	0.	0.	0.	0.	0.	0.	0.	6734.0
NET CAPITAL INVESTMENT	63341.0	40734.0	0.	0.	0.	0.	0.	0.	0.	104075.0
REVENUE:										
WASTE MANAGEMENT FEE ($ 94.94 PER TON)	0.	0.	10617.3	53403.7	53403.7	53403.7	53403.7	53403.7	53403.7	1025287.8
TOTAL REVENUE	0.	0.	10617.3	53403.7	53403.7	53403.7	53403.7	53403.7	53403.7	1025287.8
OPERATING COSTS:										
DIRECT LABOR	0.	0.	4860.0	4860.0	4860.0	4860.0	4860.0	4860.0	4860.0	97200.0
CHEMICALS & CATALYSTS	0.	0.	1378.0	2297.0	2297.0	2297.0	2297.0	2297.0	2297.0	45021.0
DRUMS & PALLETS	0.	0.	12056.0	20093.0	20093.0	20093.0	20093.0	20093.0	20093.0	393823.0
UTILITIES	0.	0.	1634.0	2724.0	2724.0	2724.0	2724.0	2724.0	2724.0	53390.0
ADMIN & GENERAL	0.	0.	2320.0	2322.0	2322.0	2322.0	2322.0	2322.0	2322.0	46438.0
PLANT MAINT	0.	0.	3914.0	6524.0	6524.0	6524.0	6524.0	6524.0	6524.0	127870.0
TAXES & INSURANCE	0.	0.	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	54000.0
DEPRECIATION	0.	0.	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	97341.0
TOTAL OPERATING COSTS	0.	0.	33729.0	46387.0	46387.0	46387.0	46387.0	46387.0	46387.0	915083.0
NET OPERATING INCOME	0.	0.	-23111.8	7016.7	7016.7	7016.7	7016.7	7016.7	7016.7	110204.8
INCOME TAX LIABILITY (0.00%)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NET INCOME AFTER TAX	0.	0.	-23111.8	7016.7	7016.7	7016.7	7016.7	7016.7	7016.7	110204.8
PLUS: DEPRECIATION	0.	0.	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	4867.0	97341.0
CASH FROM OPERATIONS	0.	0.	-18244.7	11883.7	11883.7	11883.7	11883.7	11883.7	11883.7	207545.8
NET CASH FLOW	-63341.0	-40734.0	-18244.7	11883.7	11883.7	11883.7	11883.7	11883.7	11883.7	103470.8
CUMULATIVE CASH FLOW	-63341.0	-104075.0	-122319.7	-110436.0	-98552.3	-86668.6	-74784.9	-15366.3	103470.8	0.

TABLE 24. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 3, GOVERNMENT OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 3 (56100 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
COST OF CAPITAL 6.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	8631.0	20000.0	0.	0.	0.	0.	0.	0.	0.	28631.0
TOTAL INVESTMENT	38631.0	20000.0	0.	0.	0.	0.	0.	0.	0.	58631.0
WORKING CAPITAL	0.	2863.0	0.	0.	0.	0.	0.	0.	0.	2863.0
NET CAPITAL INVESTMENT	38631.0	22863.0	0.	0.	0.	0.	0.	0.	0.	61494.0
REVENUE:										
WASTE MANAGEMENT FEE ($232.77 PER TON)	0.	0.	897.9	13058.6	13058.6	13058.6	13058.6	13058.6	13058.6	510183.7
TOTAL REVENUE	0.	0.	897.9	13058.6	13058.6	13058.6	13058.6	13058.6	13058.6	510183.7
OPERATING COSTS:										
DIRECT LABOR	0.	0.	1323.0	1323.0	1323.0	1323.0	1323.0	1323.0	1323.0	52920.0
CHEMICALS & CATALYSTS	0.	0.	138.0	230.0	230.0	230.0	230.0	230.0	230.0	9108.0
DRUMS & PALLETS	0.	0.	1205.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	79556.0
UTILITIES	0.	0.	211.0	352.0	352.0	352.0	352.0	352.0	352.0	13939.0
ADMIN & GENERAL	0.	0.	651.0	651.0	651.0	651.0	651.0	651.0	651.0	26040.0
PLANT MAINT	0.	0.	1392.0	2321.0	2321.0	2321.0	2321.0	2321.0	2321.0	91911.0
TAXES & INSURANCE	0.	0.	1292.0	1292.0	1292.0	1292.0	1292.0	1292.0	1292.0	51680.0
DEPRECIATION	0.	0.	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	58631.0
TOTAL OPERATING COSTS	0.	0.	7677.8	9643.8	9643.8	9643.8	9643.8	9643.8	9643.8	383785.0
NET OPERATING INCOME	0.	0.	-6779.9	3414.8	3414.8	3414.8	3414.8	3414.8	3414.8	126398.7
INCOME TAX LIABILITY (0.00%)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NET INCOME AFTER TAX	0.	0.	-6779.9	3414.8	3414.8	3414.8	3414.8	3414.8	3414.8	126398.7
PLUS: DEPRECIATION	0.	0.	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	1465.8	58631.0
CASH FROM OPERATIONS	0.	0.	-5314.1	4880.6	4880.6	4880.6	4880.6	4880.6	4880.6	185029.7
NET CASH FLOW	-38631.0	-22863.0	-5314.1	4880.6	4880.6	4880.6	4880.6	4880.6	4880.6	123535.7
CUMULATIVE CASH FLOW	-38631.0	-61494.0	-66808.1	-61927.5	-57046.9	-52166.3	-47285.7	25923.5	123535.7	0.

TABLE 25. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 4, GOVERNMENT OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 4 (180000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
COST OF CAPITAL 6.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	15321.0	20000.0	0.	0.	0.	0.	0.	0.	0.	35321.0
TOTAL INVESTMENT	45321.0	20000.0	0.	0.	0.	0.	0.	0.	0.	65321.0
WORKING CAPITAL	0.	3532.0	0.	0.	0.	0.	0.	0.	0.	3532.0
NET CAPITAL INVESTMENT	45321.0	23532.0	0.	0.	0.	0.	0.	0.	0.	68853.0
REVENUE:										
WASTE MANAGEMENT FEE ($131.02 PER TON)	0.	0.	5112.5	23583.3	23583.3	23583.3	23583.3	23583.3	23583.3	924860.0
TOTAL REVENUE	0.	0.	5112.5	23583.3	23583.3	23583.3	23583.3	23583.3	23583.3	924860.0
OPERATING COSTS:										
DIRECT LABOR	0.	0.	2533.0	2533.0	2533.0	2533.0	2533.0	2533.0	2533.0	101320.0
CHEMICALS & CATALYSTS	0.	0.	33.0	55.0	55.0	55.0	55.0	55.0	55.0	2178.0
DRUMS & PALLETS	0.	0.	4935.0	8225.0	8225.0	8225.0	8225.0	8225.0	8225.0	325710.0
UTILITIES	0.	0.	554.0	923.0	923.0	923.0	923.0	923.0	923.0	36551.0
ADMIN & GENERAL	0.	0.	1273.0	1273.0	1273.0	1273.0	1273.0	1273.0	1273.0	50920.0
PLANT MAINT	0.	0.	2040.0	3400.0	3400.0	3400.0	3400.0	3400.0	3400.0	134640.0
TAXES & INSURANCE	0.	0.	1575.0	1575.0	1575.0	1575.0	1575.0	1575.0	1575.0	63000.0
DEPRECIATION	0.	0.	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	65321.0
TOTAL OPERATING COSTS	0.	0.	14576.0	19617.0	19617.0	19617.0	19617.0	19617.0	19617.0	779640.0
NET OPERATING INCOME	0.	0.	-9463.5	3966.2	3966.2	3966.2	3966.2	3966.2	3966.2	145220.0
INCOME TAX LIABILITY (0.00%)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NET INCOME AFTER TAX	0.	0.	-9463.5	3966.2	3966.2	3966.2	3966.2	3966.2	3966.2	145220.0
PLUS: DEPRECIATION	0.	0.	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	1633.0	65321.0
CASH FROM OPERATIONS	0.	0.	-7830.5	5599.3	5599.3	5599.3	5599.3	5599.3	5599.3	210541.0
NET CASH FLOW	-45321.0	-23532.0	-7830.5	5599.3	5599.3	5599.3	5599.3	5599.3	5599.3	141688.0
CUMULATIVE CASH FLOW	-45321.0	-68853.0	-76683.5	-71084.2	-65484.9	-59885.7	-54286.4	29702.6	141688.0	0.

TABLE 26. PRO FORMA DISCOUNTED CASH FLOW STATEMENT FOR CASE 5, GOVERNMENT OWNED

HAZARDOUS WASTE MANAGEMENT STUDY CASE 5 (180000 TPY)
(THOUSANDS OF DOLLARS)

YEAR:	-1	0	1	2	3	4	5	20	40	TOTAL
COST OF CAPITAL 6.00%										
CAPITAL INVESTMENT:										
MINE	30000.0	0.	0.	0.	0.	0.	0.	0.	0.	30000.0
PROCESS PLANT	15000.0	15946.0	0.	0.	0.	0.	0.	0.	0.	30946.0
TOTAL INVESTMENT	45000.0	15946.0	0.	0.	0.	0.	0.	0.	0.	60946.0
WORKING CAPITAL	0.	3095.0	0.	0.	0.	0.	0.	0.	0.	3095.0
NET CAPITAL INVESTMENT	45000.0	19041.0	0.	0.	0.	0.	0.	0.	0.	64041.0
REVENUE:										
WASTE MANAGEMENT FEE ($ 71.16 PER TON)	0.	0.	922.3	12809.0	12809.0	12809.0	12809.0	12809.0	12809.0	500474.7
TOTAL REVENUE	0.	0.	922.3	12809.0	12809.0	12809.0	12809.0	12809.0	12809.0	500474.7
OPERATING COSTS:										
DIRECT LABOR	0.	0.	1658.0	1658.0	1658.0	1658.0	1658.0	1658.0	1658.0	66320.0
CHEMICALS & CATALYSTS	0.	0.	165.0	275.0	275.0	275.0	275.0	275.0	275.0	10890.0
DRUMS & PALLETS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UTILITIES	0.	0.	464.0	773.0	773.0	773.0	773.0	773.0	773.0	30611.0
ADMIN & GENERAL	0.	0.	900.0	900.0	900.0	900.0	900.0	900.0	900.0	36000.0
PLANT MAINT	0.	0.	1581.0	2635.0	2635.0	2635.0	2635.0	2635.0	2635.0	104346.0
TAXES & INSURANCE	0.	0.	1479.0	1479.0	1479.0	1479.0	1479.0	1479.0	1479.0	59160.0
DEPRECIATION	0.	0.	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	60946.0
TOTAL OPERATING COSTS	0.	0.	7770.7	9243.7	9243.7	9243.7	9243.7	9243.7	9243.7	368273.0
NET OPERATING INCOME	0.	0.	-6848.3	3565.4	3565.4	3565.4	3565.4	3565.4	3565.4	132201.7
INCOME TAX LIABILITY (0.00%)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NET INCOME AFTER TAX	0.	0.	-6848.3	3565.4	3565.4	3565.4	3565.4	3565.4	3565.4	132201.7
PLUS: DEPRECIATION	0.	0.	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	1523.6	60946.0
CASH FROM OPERATIONS	0.	0.	-5324.7	5089.0	5089.0	5089.0	5089.0	5089.0	5089.0	193147.7
NET CASH FLOW	-45000.0	-19041.0	-5324.7	5089.0	5089.0	5089.0	5089.0	5089.0	5089.0	129106.7
CUMULATIVE CASH FLOW	-45000.0	-64041.0	-69365.7	-64276.6	-59187.6	-54098.6	-49009.5	27326.0	129106.7	0.

shown should not be construed as precisely accurate estimates.

The sensitivity of the base case unit cost to the size of the storage plant is presented in Figure 35. The sensitivity of the base case unit cost to changes in the return on investment is presented in Figure 36. Figure 37 presents the sensitivity of the base case unit cost to the cost of the mine.

As shown in Figure 35, the unit cost per ton of received waste would be reduced rapidly as the plant size is increased from 56,400 tons per year (Case 3) to 375,000 tons per year (Case 1), but it gradually levels off as the plant size is increased beyond 375,000 tons per year.

As shown in Figure 36, the unit cost per ton is sensitive to the return on investment. If, for example, a return of 7.5 percent instead of 10 percent was acceptable, the waste management fee could be reduced from approximately $130 to $119, an 8 percent reduction.

The sensitivity of the unit cost to the cost of the mine is presented in Figure 37. Changing the mine cost from $30 million to 50 million increased the unit costs from approximately $131 to $171.

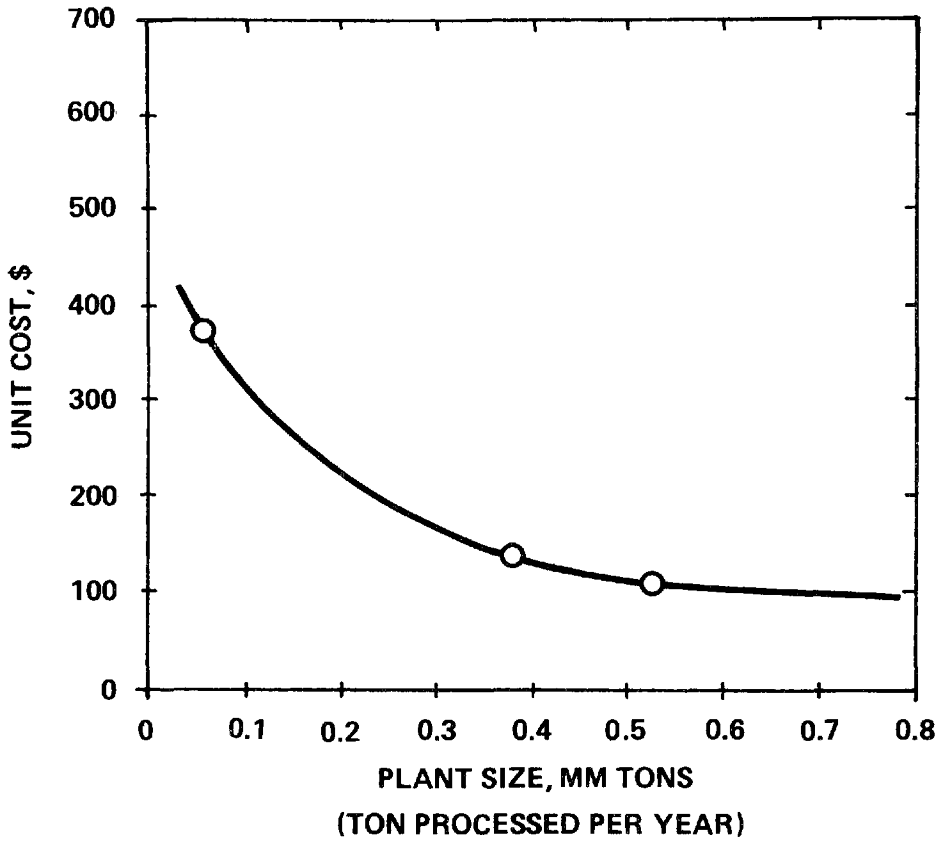


Figure 35. Sensitivity of the base case unit cost to changes in plant size.

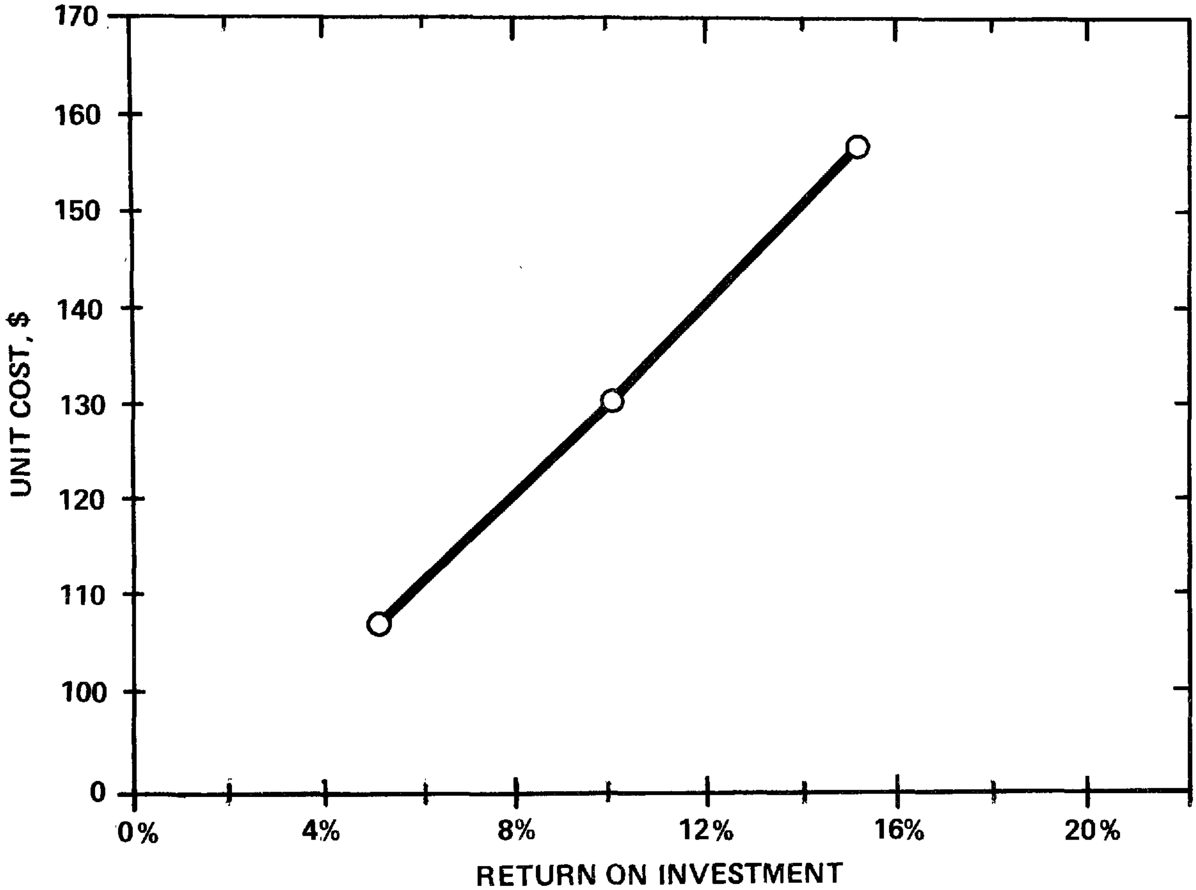


Figure 36. Sensitivity of the base case unit cost to changes in the cost of capital.

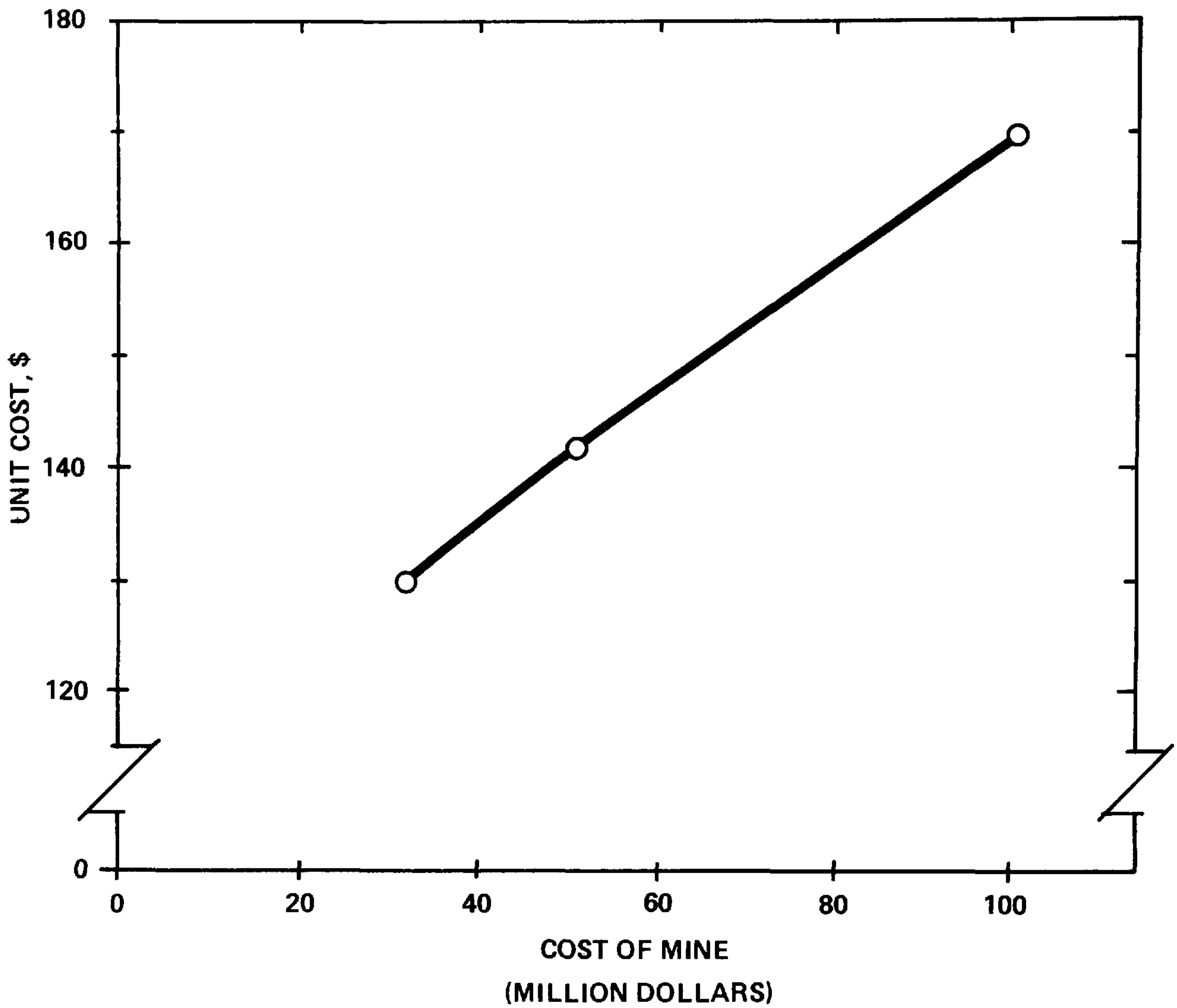


Figure 37. Sensitivity of the base case unit cost to changes in the cost of the mine.

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APPENDIX A*

SUMMARY OF U.S. HAZARDOUS WASTE QUANTITIES

TABLE A-1. HAZARDOUS WASTE QUANTITIES (U.S.)
(million metric tons annually)

INDUSTRY	DRY BASIS	WET BASIS
1. BATTERIES	0.005	0.010
2. INORGANIC CHEMICALS	2.000	3.400
3. ORGANIC CHEMICALS, PESTICIDES, EXPLOSIVES	2.150	6.860
4. ELECTROPLATING	0.909	5.276
5. PAINTS	0.075	0.096
6. PETROLEUM REFINING	0.600	1.300
7. PHARMACEUTICALS	0.062	0.065
8. PRIMARY METALS	17.398	20.356
9. LEATHER TANNING AND FINISHING	0.045	0.146
10. TEXTILES DYEING AND FINISHING	0.048	1.770
11. RUBBER AND PLASTICS	0.205	0.785
12. SPECIAL MACHINERY	0.102	0.162
13. ELECTRONIC COMPONENTS	0.016	0.023
14. WASTE OIL RE-REFINING	0.057	0.057
TOTALS (TO DATE)	23.667	40.432

*Note: These tables are summary of the reports on the assessment of industrial hazardous waste practices. These tables are obtained from the project offices.

TABLE A-2. HAZARDOUS WASTE GROWTH PROJECTIONS

INDUSTRY	Amount (Mill. Metric Tons/Yr.) 1974 DRY	1974 WET	1977 DRY	1977 WET	1983 DRY	1983 WET	% GROWTH '74 - '83
1. BATTERIES	0.005	0.010	0.082	0.164	0.105	0.209	2000
2. INORGANIC CHEMICALS	2.000	3.400	2.300	3.900	2.800	4.800	40
3. ORGANIC CHEMICALS, PESTICIDES AND EXPLOSIVES	2.150	6.860	3.500	11.666	3.800	12.666	77
4. ELECTROPLATING	0.909	5.276	1.316	4.053	1.751	5.260	92
5. PAINT AND ALLIED PRODUCTS	0.075	0.096	0.084	0.110	0.105	0.145	30
6. PETROLEUM REFINING	0.610	1.300	0.647	1.400	0.693	1.500	12
7. PHARMACEUTICALS	0.062	0.065	0.070	0.074	0.104	0.108	68
8. PRIMARY METALS SMELTING AND REFINING	17.398*	20.356*	18.211*	21.307*	21.110*	24.700*	21
9. TEXTILES DYEING AND FINISHING	0.048	1.770	0.500	1.870	0.179	0.716	373
10. LEATHER TANNING	0.045	0.146	0.050	0.143	0.068	0.214	51
11. SPECIAL MACHINERY	0.102	0.163	0.094	0.153	0.157	0.209	54
12 ELECTRONIC COMPONENTS	0.016	0.023	0.023	0.051	0.032	0.070	200
13. RUBBER AND PLASTICS	0.205	0.785	0.242	0.944	0.299	1.204	46
14. WASTE OIL RE-REFINING	0.057	0.057	0.074	0.074	0.144	0.144	253
TOTALS (TO DATE)	23.667	40.432	27.143	45.909	31.347	51.945	32 63**

* This figure excludes primary metals industry slag and foundry sand

** Excluding primary metals

TABLE A-3. EPA REGIONAL CENTER OF HAZARDOUS WASTES

INDUSTRY	EPA REGION	% TOTAL
1. BATTERIES	V	36.2
2. INORGANIC CHEMICALS	VI	45.5
3. ORGANIC CHEMICALS, PESTICIDES, AND EXPLOSIVES	VI	54.6
4. PHARMACEUTICALS	II	51.5
5. METALS MINING	IX	51.6
6. PRIMARY METALS	V	38.6
7. PAINTS	V	31.6
8. ELECTROPLATING	V	44.4
9. PETROLEUM REFINING	VI	43.1
10. TEXTILES	IV	58.8
11. LEATHER TANNING	I	38.3
12. RUBBER AND PLASTICS	IV	24.5
13. SPECIAL MACHINERY	V	25.0
14. ELECTRONIC COMPONENTS	II	28.0
15. WASTE OIL RE-REFINING	V	30.1

TABLE A-4. HAZARDOUS WASTE PROFILE

(MM METRIC TON, WET)

INDUSTRY	1974	WASTELOAD 1977	1983	PERCENT MANAGED OFF-SITE
PRIMARY METALS	20	21	25	2
ORGANIC CHEMICALS	7	12	13	20
ELECTROPLATING	5	4	5	70
INDUSTRIAL INORGANIC CHEMICALS	4	4	5	15
TEXTILE MILL PRODUCTS	2	2	1	5
PETROLEUM REFINING	1	1	1	60
7 OTHERS	1	2	2	75
TOTAL	40	46	52	18

TABLE A-5. EPA REGION RANKINGS:HAZARDOUS WASTE GENERATION

EPA REGION (RANK)	% OF TOTAL
I (7)	3.0
II (6)	4.3
III (2)	21.6
IV (5)	7.8
V (1)	31.0
VI (3)	14.2
VII (10)	0.9
VIII (8)	1.7
IX (4)	13.8
X (8)	1.7

TABLE A-6. STATE HIGHLIGHTS: HAZARDOUS WASTE GENERATION

(METRIC TONS - DRY WEIGHT)

STATE	QUANTITY	% TOTAL
(1) PENNSYLVANIA	(1) 3,278,328	(1) 15.6%
(2) OHIO	(2) 2,899,797	(2) 13.8%
(3) INDIANA	(3) 2,268,171	(3) 10.8%
(4) TEXAS	(4) 2,124,047	(4) 10.1%
(5) ILLINOIS	(5) 1,378,351	(5) 6.6%
(6) MICHIGAN	(6) 1,224,139	(6) 5.8%
(7) WEST VIRGINIA	(7) 778,288	(7) 3.8%
(8) NEW YORK	(8) 739,850	(8) 3.7%
(9) LOUISIANA	(9) 739,850	(9) 3.5%
(10) ALABAMA	(10) 689,600	(10) 3.28%
(11) MARYLAND	(11) 687,507	(11) 3.27%
(12) CALIFORNIA	(12) 659,189	(12) 3.14%
(37) VIRGINIA	(37) 32,872	(37) 0.16%
(50) NORTH DAKOTA	(50) 2,838	(50) 0.01%

APPENDIX B

SPECIFIC DESIGN CRITERIA FOR THE BASE CASE SURFACE FACILITIES

Criteria used for the design of the surface equipments are summarized below.

Receiving and Unloading Stations

- Types A and B waste tank car unloading — 90 minutes
- Types A and B waste tank truck unloading — 60 minutes
- Type C hopper car and dump truck unloading — 60 minutes
- Drummed waste box car unloading — 90 minutes
- Drummed waste container truck unloading — 60 minutes

Waste Storage

- The capacity of each tank is one day's volume of a particular waste plus 10% free board, except two day's capacity for tanks of acid and alkaline wastes
- Average liquid waste density is assumed to be 9 lbs/gal.
- Mixing power is 1 HP per thousand gallon of Type A waste and 2 HP per thousand gallons of Type B waste.
- Transfer pumps have connected spares
- Storage bins for Type C waste have one day's capacity — 150 tons (90 lbs per cu. ft). Transfer conveyor capacity is 25 tons per hour.

Waste Treatment

Type A-1, Chromate Waste

- Waste composition is shown in Table 7.
- Cr^{+6} is reduced to Cr^{+3} under acidic condition. The reaction is carried out continuously. Thirty minutes residence time is allowed at design capacity.

Type A-2, Cyanide Waste

- Waste composition is shown in Table 7.
- Cyanide waste is reacted with chlorine and caustic according to

$$2\ NaCN + 5\ Cl_2 + 12\ NaOH - 10\ NaCl + 2Na_2CO_3 + N_2 + 6H_2O$$

- Four hours residence time is allowed for the reactions

Type A-3, Acid and Caustic Waste

- Waste composition is shown in Table 7.
- Waste are neutralized by blending them together along with lime addition.
- Twenty minutes residence time is allowed for neutralization.

Type A Precipitation

- Precipitation with lime follows blending of non-reactive wastes and the above treated wastes (one day's surge).
- Thirty minutes residence time is allowed for the precipitation.

Type A Dewatering

- Rotary vacuum belt filter at a filtration rate of 5 gal. per per hour per square feet.
- Filter cake is 40% solid, 90 lbs per cubic feet.

Type B-1, Acid and Caustic Waste

- Acid and caustic sludge wastes are mixed together along with lime to neutralize excess acidity.
- Thirty minute residence time is provided for neutralization.

Type B Dewatering

- Dewatering of inorganic and organic wastes is accomplished batchwise in automatic pressure filters.
- Filter cake is at minimum 40% solids. Five tons per 90 minute filter cycle is processed.

Effluent Treatment

- Effluent Treatment operates three shifts per day.
- Effluent storage capacities are:
  - 2 days for all filtrates
  - 1 day for all process wastewater
  - Runoffs from 6-inch rains on 10 acres, 0.9 run-off coefficient
- Vapor-recompression evaporation system capacity is 150 gpm.
- 70% water is evaporated at 100 kwh/1000 gallons evaporated.
- Evaporator - crystallizer capacity is 100 tons per day and filter capacity is 5 tons per hour.
- 75 gpm vapor-recompression evaporator is provided to work off contaminated storm runoff (15 days workoff).
- Oily waste incinerator capacity is 600 gallons per hour. Heat release is 77 million Btu per hour assuming heating value of 15,000 Btu per pound.

Containerization

- 300 drums per box car is unloaded in 90 minutes
- 10,000 drums storage area (5 day supply) is provided.
- 180 pallets per truckload is unloaded in one hour.
- 2500 pallets storage area (5 day supply) is provided.
- Drum filling rate is 30 drums per hour per line.
- Each drum contains 625 lbs of waste (52 gallons per drum, 12 lbs/gal).
- Total Containerization capacity is 40% above the design rate of 585 tons per day based on two shift operation.

Staging

- Drums are stored on pallets (4 drums on each pallet).
- 2 day storage is provided in staging area.
- Types C and D waste in drums (50 TPD each) are transferred from their storage area directly to the shaft area for lowering into the mine.

APPENDIX C

TABLE C. BASE CASE EQUIPMENTS AND COSTS

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
SURFACE OPERATION		
RECEIVING & UNLOADING		
Tank Car & Tank Truck Unloading	18 Pumps (5-100 gpm, 4-100 gpm, 5-200 gpm, 4-200 gpm)	104,000
Drum Handling - Opening, Unloading, Pumping	9-Pumps, 2-Drum Head Removers, 2-500 Gallon Tanks, 4-Electric Forklifts, 4-Tractor Trailers	326,000
Dump Truck Unloading	2 - 10' x 10' x 6' Hopper & Conveyors	35,000
Dump Car Unloading	12' x 26' x 12' Hopper & Conveyor	45,000
Transfer Conveyor System (To Storage Bins)	12"Ø x 40'H Screw Elevator Conveyor, 12"Ø x 75'L Screw Conveyor, 16"Ø x 45'H Screw Elevator Conveyor 14"W x 220'L Belt Conveyor, 2 - 14"Ø x 75'L Screw Conveyor	311,000
Transfer Conveyor System (To Filter/Surge Bins)	2 - 12"Ø x 75'L Screw Conveyor, 12"Ø x 30'H Screw Elevator Conveyor 12" Ø x 45'L Screw Conveyor, 12"Ø x 100'L Screw Conveyor	224,000
Drum Unloading	6 - Electric Forklifts (4 - 3,000 lbs, 2 - 10,000 lbs capacity)	180,000
		1,225,000
WASTE STORAGE & TREATMENT		
TYPE A WASTE:		
Chromate Waste, A-1		
Storage (Chromate Waste)	4 - 25,000 Gallon Tanks, 4 - 25 HP Agitators, 4 - 1.5 HP Feed Pumps	206,000
pH Adjustment	400 Gallon Vessel	42,000
Chromate Reduction	1000 gallon Vessel, 2.5 HP Agitator	52,000
Sulfur Dioxide Feeding	Package SO_2 Feed System Tank Car Air Padding Unit	60,000
Sulfuric Acid Feeding	6000 Gallon Tank 1 HP Pump	20,000
		380,000

Continued

TABLE C (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Cyanide Waste, A-2		
Storage (Cyanide Waste)	4 - 25,000 Gallon Tanks, 4 - 25 HP Agitators, 4 - 1.5 HP Feed Pumps	181,000
Cyanide Oxidation	2 - 3600 Gallon Vessels, 2 - 7.5 HP Agitators, 3 - 1 HP Pumps	169,000
Chlorine Feeding	2 - Package Chlorine Feed Systems with Air Padding Units	100,000
Caustic Feeding	2 - 10,000 Gallon Tanks, 2 - 2 HP Pumps, 2 - 3/4 HP Feed Pumps	42,000
		492,000
Acid/Alkaline Waste, A-3		
Storage (Acid & Alkaline Waste)	4 - 50,000 Gallon Tanks, 4 - 25 HP Agitators, 5 - 1.5 HP Feed Pumps	260,000
Neutralization	1200 Gallon Reactor	90,000
		350,000
Non-Reactive Waste, A-4		
Storage (Non-Reactive Waste)	4 - 50,000 Gallon Tanks, 4 - 25 HP Agitation, 4 - 2.5 HP Feed Pumps	270,000
		270,000
Lime Slaking & Feed System		
Lime Unloading & Storage	32' x 10' x 8' Hopper, 50'H Bucket Elevator, 16"W x 50'L Conveyor Belt, 2 - 100 Ton Storage Bins	113,000
Lime Slaking	Lime Feeder, Package Slaker, 750 Gallon Slaker Tank	30,000
Slaked Lime Feeding	10,000 Gallon Lime Slurry Tank, 15 HP Agitator, 2 - 1 HP Pumps, 10,000 Gallon Lime Feed Tank	57,000
		200,000

Continued

TABLE C (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Type A Waste Precipitation		
Blend/Surge	4 - 50,000 Gallon Tanks, 8 - 25 HP Agitators, 4 - 2.5 HP Feed Pumps	300,000
Precipation	2 - 3,000 Gallon Vessels, 2 - 6 HP Agitators, 3 - 6 HP Slurry Pumps, 3 - 3/4 HP Lime Slurry Pumps	180,000
		480,000
Type A Waste Filtration		
Filtration	2 - 2,700 sq ft Vacuum Filters, 2-3 HP Filtrate Pumps	753,000
Cake Storage	2 - 3' x 26' x 6' Bins, 4 - 9"Ø x 30'L Screw Conveyors, 2 - 10"Ø x 30'H Elevator Conveyors, 2 - 9"Ø x 15'L Transfer Conveyor	177,000
Ferric Chloride Feeding	6,000 Gallon Tank, 2 - 1 HP Pumps, 2 - 1/3 HP Feed Pumps	20,000
		950,000
TYPE B WASTE:		
Acid/Alkaline Slurry Waste, B-1		
Acid/Alkaline Slurry Storage	4 - 25,000 Gallon Tanks, 4 - 25 HP Agitators, 4 - 1 HP Pumps	204,000
Neutralization	900 Gallon Vessel, 2.5 HP Agitator	86,000
		290,000
Acid/Alkaline Slurry, B-1 Filtration		
Filter Feed	2,500 Gallon Surge Tank, 1.5 HP Agitator, 3 - 7.5 HP Pumps	12,000
Filtration	2,560 sq. ft., 4' x 4' x 80 Chamber, Plate and Frame Filter Press, Static Mixer for $FeCl_3$ Mixing	120,000
Filtrate Storage	1,000 Gallon Tank 4 HP Pump	4,000
Filter Cake Storage & Transfer	6' x 20' x 4' (480 cu ft) Bin, 9"Ø x 30'L Screw Conveyor	84,000
		220,000

continued

TABLE C(continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Inorganic Slurry, B-2 Filtration		
Storage (Inorganic Slurry Waste)	4 - 50,000 Gallon Tanks, 8 - 25 HP Agitators, 4 - 4 HP Pumps	280,000
Feed Surge	2,500 Gallon Surge Tank, 1.5 HP Agitator	15,000
Filtration	2 - 2,500 sq ft (4' x 4' x 80 Chamber), Plate and Frame Filter Press, Static Mixer for $FeCl_3$ Mixing	119,000
Filtrate Storage	2,000 Gallon Tanks, 2 - 4 HP Pumps	8,000
Filter Cake Storage & Transfer	2 - 480 cu ft Bins, 2 - 9"Ø x 30'L Conveyor	72,000
Cake Transfer	120' Conveyor System	97,000
		591,000
Organic Slurry, B-3 Filtration		
Storage (Organic Slurry Waste)	4 - 25,000 Gallon Tanks, 4 - 25 HP Agitators, 4 - 2 HP Pumps	198,000
Filter Feed Surge	2,500 Gallon Tank, 1.5 HP Agitator, 1/4 HP Pump, 3 - 6 HP Pumps	17,000
Filtration	$FeCl_3$ Mixer (Static Mixer), 2,560 sq ft Plate & Frame Filter Press	108,000
Filtrate Storage	1,000 Gallon Tank, 2 - 4 HP Filtrate Pumps	7,000
Filter Cake Storage & Transfer	2 - 6' x 20' x 4' Bins, 150' Conveyor System	140,000
		470,000
TYPE C WASTE:		
Storage (Waste C - Bulk)	6 - 120 Ton (12' x 12' x 28') Bins, 6 - Screw Feeders	115,000
WASTE CONTAINERIZATION		
Filter Cake Surge	6 - 150 Ton Capacity Bins, 6 - 10"Ø x 25'L Screw Feeders	144,000

continued

TABLE C(continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Drum Feed System	6 - 1 Ton Capacity Hoppers, 6 - Vibrating Feeders	21,000
Drum Handling & Containerization (Subcontracted Package)	950' (30"-40"W) Empty Drum Conveyor System, 600' (30'W) Containerization Conveyor System, 350' (60"W) Pallets Conveyor System, 6 - Automatic Drum Filling Units, 6 - Automatic Lidding Units, 6 - Automatic Labeling Units, 6 - Automatic Drum Palletizing Units	1,650,000
Drum Moving	1 - 3,000 lbs Capacity Electric Forklift, 3 - 10,000 lbs Capacity Electric Forklifts	130,000
		1,945,000
PLANT WASTEWATER TREATMENT:		
Filtrate Concentration		
Filtrate Storage	2 - 175,000 Gallon Tanks, 2 - 5 HP Feed Pumps	170,000
Evaporation (Filtrate)	150 gpm Vapor Recompression Evaporator— Package Unit	1,750,000
Condensate Storage	140,000 Gallon Tank	80,000
Evaporation (Contaminated Storm Water)	75 gpm Vapor Recompression Evaporator - Package Unit	1,120,000
		3,120,000
Brine Crystallization		
Brine Surge	4,500 Gallon, 10 HP Agitator, 2 - 2 HP Feed Pumps	5,000
Crystalization (Evaporative)	100 TPD Package Evaporator - Crystallizer, 2 - 5 TPH Centrifugal Filters, 2 - 3/4 HP Slurry Pumps, 1,000 Gallon Slurry Tanks, 650 Gallon Centrate Tanks	585,000
Filter Cake Transfer & Storage	105' Cake Conveyor System, 48 cu ft Capacity Bin	60,000
		650,000
Oily Waste Incineration		
Waste Storage	2 - 25,000 Gallon Tanks, 2 - 2.5 HP Agitator, 2 - 1/2 HP Feed Pumps,	112,000

continued

TABLE C (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Incineration	50 TPH (600 Gallons/Hour) Package Incinerator with Scrubber	368,000
		480,000
MONITORING & ANALYTICAL INFORMATION		
Sample Analysis & Mine Environment Monitoring	Standard Lab Equipment, Gas Chromatograph, Nephalometer (Particulate in air), Atomic Absorption Spectrophotometer, Organic Carbon Analyzer	200,000
SUBSURFACE OPERATION		
HOISTING		
Loading on Hoist System	Automation of Existing Hoist System, 3 - New Skips, 3 - Forklifts (Electic)	252,000
Unloading from Hoist & Staging	3 - Forklifts (14,000 lb capacity diesel forklifts)	99,000
HAULING		
Loading on Truck & Transfer to Storage Area	8 - Flat Bed Trailers (25 ft.) 3 - Diesel Tractors	183,000
STORAGE		
Storage Cell Preparation & Emplacement	3 - Forklifts, 3 - Haul Trucks, 2 - Front-end Loaders, 2 - Utility Vehicles, 2 - Floor Graders, 2 - Roof Bolters, 2 - Rollers, 2 - Water Trailers, 2 - Scalers, 2 - Brush	1,170,000
VENTILATION		
Ventilation	1 - Main Fan 1 - Backup Fan 6 - Buster Fans	82,000

continued

TABLE C (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
MISCELLANEOUS SERVICES	1 - First Aid Vehicle, 2 - Decontamination Vehicles, 2 - Fire Control Vechiles, 2 - Utility Repair Vehicles, 4 - Personnel Carriers	165,000
PLANT UTILITIES		
Boiler	20,000 lbs/hr, 150 psi Package Boiler	60,000
Cooling Tower	800 - 3,000 gpm Package Cooling Tower, 3 - 100 gpm pumps	170,000
Electric System	Main Transformer, Motor Control Center Yard Lighting	70,000
Drainage System	Storm Drainage, Sewage System	130,000
Yard Safety	Fire Protection System, Washdown Stations	60,000
Compressed Air System	100 psi, 150 U SCFM Package Air Compression Unit	70,000
		560,000

APPENDIX D

TABLE D. BASE CASE CIVIL STRUCTURES, BUILDINGS, MINE REHABILITATION, AND COSTS

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
	R&F - Roof and Floor; L - Lighting; P - Plumbing; HVAC - Heating, Ventillation, Air Conditioning; SF - Steel Frame; MW - Masonry Wall; 2ST - Two Stories	
SITE DEVELOPMENT		
Site Preparation	12.8 Acres Site Clearing,3,300' x 7'H Fencing, 30,000 cu yd cut/fill Earthwork	90,000
Grading	8,600 sq yd Concrete Paving, 5,700 sq yd Asphalt Paving, 3,200 sq yd Grassed Area, 24,000 sq yd Graveled Area, 41,500 sq yd Base Preparation	166,000
Railroad Track	2,200 ft New Track, 2,200 ft Remove Old Track	104,000
		360,000
RECEIVING & UNLOADING		
Truck Scale Office & Pad	300 sq ft Office, R&F, MW, L&P, HVAC 660 sq ft Pad, R&F, L	50,000
Rail Scale Office & Pad	300 sq ft Office, R&F, MW, L&P, HVAC 720 sq ft Pad, R&F, L	51,000
Tank Truck Unloading	1,000 sq ft Platform 1,200 sq ft Building - R&F, MW, SF, L	66,000
Container Truck Unloading	2,500 sq ft Platform 2,500 sq ft Building - R&F, MW, SF, L	112,000
Dump Truck Unloading	700 sq ft Building - R&F, SF, L, 3 side MW	31,000
Tank & Hopper Car Unloading	4,375 sq ft Building - R , L, Gravel Floor	54,000
Box Car Unloading	720 sq ft Platform 1,800 sq ft Building - R, L	46,000
Drum Unloading	1,800 sq ft Platform 3,520 sq ft Building - R, L	112,000
Chemical Unloading	6,000 sq ft - R, Gravel Floor, SF, L	73,000
Chlorine Unloading	1,200 sq ft - R, Gravel Floor, SF, L	15,000
		610,000

Continued

TABLE D (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
WASTE STORAGE		
Storage Tank Area	30,000 sq ft Graveled - Diked Area	17,000
Drummed Waste Storage	2 x 27,600 sq ft, 2ST, R&F, MW, SF, L, HVAC	733,000
		750,000
SERVICE BUILDINGS		
Adminstration Building	4,000 sq ft, R&F, SF, MW, L&P, HVAC, Furniture	240,000
Safety - Medical Building	2,925 sq ft, R&F, SF, MW, L&P, HVAC, Furniture, Standard Equipment	200,000
Laboratory	2,600 sq ft, R&F, SF, MW, L&P, HVAC, Furniture	210,000
Equipment Storage Building	7,200 sq ft, R, Graveled Floor, Equipment	260,000
Warehouse	4,125 sq ft, R&F, SF, MW, L&P, Equipment	170,000
Shops	4,800 sq ft, R&F, SF, MW, HV, L&P, Equipment	260,000
Drum Cleaning Building	1,925 sq ft, R&F, SF, MW, HV, L&P, Equipment	90,000
		1,430,000
PROCESS BUILDINGS		
Waste Treatment Building	2 x 5,250 sq ft, 2ST, R&F, MW, SF, HV, L&P	400,000
Filtration Building	2 x 11,100 sq ft, 2ST, R&F, SF, MW, HV, L&P	840,000
Containerization Building	2 x 40,250 sq ft, 2ST, R&F, SF, MW, HV, L&P	836,000
Staging Building	2 x 44,000 sq ft, 2ST, R&F, SF, MW, HV, L&P	920,000
		2,996,000
PLANT WASTEWATER TREATMENT BUILDINGS		
Wastewater Collection Ponds	55,000 Gallon Lined Pond 1.6 MG Storm Water Pond	110,000

continued

TABLE D (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
Wastewater Solid Filtration Building	500 sq ft, R&F, SF, MW, HV, L&P	30,000
Boiler House	750 sq ft, R&F, SF, MW, HV, L&P	40,000
		180,000
MINE REHABILITATION		
Production Shaft	Rehabilitate Existing 16 ft Concrete Lined Shaft - Grout Water Bearing Sandstone, Rehabilitate Shaft Walls and Shaft Timbers	1,250,000
Loading & Unloading Station Rehabilitation	Convert Existing Bulkloading Station to Pallet Loading, New Shaft Housing at Surface and Underground	36,000
Man Shaft	Minor Rehabilitation of Existing Man Shaft - Grouting, Rehabilitate Man Station	256,000
Underground Staging Area	7 Rooms (40' x 40' x 22') - Waste Salt Removal, Scaling of Roof, Roof Bolting, Floor Grading, Provide Lighting	52,000
Haulways	Improve 8,000 ft of haulways and 8000 ft of Access Roads - Scale . Loose Rocks , Roof Bolting as Needed, Floor Grading, Construct 20 Stopping and Haulway Doors, Provide Lighting	63,000
Storage Cells	Prepare 24 Cells Initially - Remove Waste Salts (300 tons per room), Scale Loose Rocks, Install Roof Bolts, Grade Floor	92,000
		1,749,000
VENTILATION SYSTEM (NEW)		
Ventilation Shaft	Drill New 8' x 1,400' Ventilation Shaft - Case and Outfit	2,750,000
Ventilation System	Construct 50 New Stoppings and Remove Existing 50 Stoppings, 6 New Ventilation Raises (600 ft), 10,000 ft New Drifts	1,687,000
		4,437,000

continued

TABLE D (continued)

SERVICE	DESCRIPTION	INSTALLED EQUIPMENT COST, $
UNDERGROUND SERVICE BUILDINGS		
Office	400 sq ft, R&F, MW, L&P, Furniture	16,000
Record Room	600 sq ft, R&F, MW, L&P, Furniture	24,000
Lunch Room	600 sq ft, R&F, MW, L&P, Furniture	24,000
Rest Rooms	Two 150 sq ft, R&F, MW, L&P, Furniture	12,000
First Aid Station	300 sq ft, R&F, MW, L&P, Furniture	12,000
Stock Rooms	900 sq ft (400, 300, 200 sq ft), R&F, MW, L&P, Furniture	37,000
Vehicle Service Station	1,000 sq ft Open Area with Workbench	8,000
Repair Shop	900 sq ft Shop Area with Workbench and Equipment	20,000
Decontamination Room	2,400 sq ft, roof and 3 side walls, L&P, Equipment	78,000
		231,000

APPENDIX E

TABLE E. BASE CASE LABOR REQUIREMENT AND COSTS

DIRECT LABOR	Men/Shift			Men/Day	Rate $/Hr	Annual Cost $/Yr
SURFACE OPERATION:						
Waste Receiving & Unloading						
Weighmaster/Dispatcher	2	2	0	4	9.50	91,200
Operator, Tow Tractor	2	1	0	3	10.50	75,600
Operator, Tank Truck & Car Unloading	2	2	0	4	10.50	100,800
Operator, Hopper Car & Truck Unloading	1	0	0	1	10.50	25,200
Operator, Forklift	5	0	0	5	10.50	126,000
Labor, Drum Cleaning	2	2	0	4	8.70	83,520
Labor, General	2	2	0	4	8.70	83,520
Foreman	1	1	0	2	11.10	53,280
	17	10	0	27		639,120
Waste Treatment						
Operator, Type A Waste Treatment	2	2	0	4	10.50	100,800
Operator, Type A Waste Precipitation	1	1	0	2	10.50	50,400
Operator, Type A Waste Filtration	1	1	0	2	10.50	50,400
Operator, Chemical Feed	2	2	0	4	10.50	100,800
Operator, Type B Treat & Filtration	2	2	0	4	10.50	100,800
Labor, Type B Waste Filtration	1	1	0	2	8.70	41,760
Foreman	1	1	0	2	11.10	53,280
	10	10	0	20		498,240
Containerization						
Operator, Drum Unloading Forklift	1	1	0	2	10.50	50,400
Labor, Drum Unloading	3	3	0	6	8.70	125,280
Labor, Drum Storage	2	2	0	4	8.70	83,500
Foreman, Drum Unloading	1	1	0	2	11.10	53,280
Operator, Fill Station	7	7	0	14	10.50	352,800
Labor, Drum Handling	3	3	0	6	8.70	125,280
Operator, Forklift	3	3	0	6	10.50	151,200
Foreman	2	2	0	4	11.10	106,560
	22	22	0	44		1,048,300
Plant Wastewater Treatment						
Operator, Waste Concentration System	1.5	1.5	1.5	4.5	10.50	113,400
Operator, Boiler	1	1	1	3	10.50	75,600
Labor	1	1	1	3	8.70	62,640
Operator, Incinerator	.5	.5	.5	1.5	10.50	37,800
Foreman	1	1	1	3	11.10	79,920
	5	5	5	15		369,360
TOTAL SURFACE OPERATION	54	47	5	106		2,555,020

continued

TABLE E (continued)

	Men/Shift			Men/Day	Rate $/Hr	Annual Cost $/Yr
SUBSURFACE OPERATION:						
Loading, Hoisting & Unloading						
Operator, Loading Forklift	2	2	0	4	10.50	100,800
Labor, Loading	1	1	0	2	8.70	41,760
Operator, Hoisting	1	1	0	2	10.50	50,400
Operator, Unloading Forklift	2	2	0	4	10.50	100,800
Labor, Unloading	1	1	0	2	8.70	41,760
Foreman	1	1	0	2	11.10	53,280
	8	8	0	16		388,800
Hauling						
Operator, Haul Truck	2	2	0	4	10.50	100,800
Labor, Hauling	1	1	0	2	8.70	41,760
Foreman	.5	.5	0	1	11.10	26,640
	3.5	3.5	0	7		169,200
Storage						
Operator, Forklift	1	1	0	2	10.50	50,400
Labor	2	2	0	4	8.70	83,500
Foreman	.5	.5	0	1	11.10	26,640
	3.5	3.5	0	7		160,560
Storage Cell & Haulway Preparation						
Operator, Frontend Loader	1	1	0	2	10.50	50,400
Operator, Haul Truck	2	2	0	4	10.50	100,800
Operator, Grader	1	1	0	2	10.50	50,400
Operator, Roof Bolter	2	2	0	4	10.50	100,800
Operator, Scaler	1	1	0	2	10.50	50,400
Labor	1	1	0	2	8.70	41,760
Foreman	.5	.5	0	1	11.10	26,640
	8.5	8.5	0	17		421,200
TOTAL SUBSURFACE OPERATION	23.5	23.5	0	47		1,139,760
MAINTENANCE LABOR						
SURFACE OPERATION:						
Welder	0	0	1	1	11.10	26,640
Machinist	0	1	2	3	11.10	79,920
Electrician	0	1	2	3	11.10	79,920
Mechanic	0	1	2	3	11.10	79,920
Pipefitter	0	1	1	2	11.10	53,280
HVAC	1	1	1	3	11.10	79,920

continued

TABLE E (continued)

	Men/Shift			Men/Day	Rate $/Hr	Annual Cost $/Yr
SURFACE OPERATION (Continued)						
Operator, Equipment	0	0	2	2	10.50	50,400
Technician, Instrument	1	1	1	3	11.10	79,920
Foreman	0	1	2	3	11.10	79,920
Mechanic, Vehicle	0	1	1	2	11.10	53,280
Mechanic Helper, Vehicle	0	0	1	1	9.50	22,880
	2	8	16	26		685,920
SUBSURFACE OPERATION:						
Hoist Serviceman	1	1	1	3	11.10	79,920
Shaft Repairman	0	0	1	1	11.10	26,640
Ventilation Serviceman	1	1	1	3	11.10	79,920
Mechanic	1	1	1	3	11.10	79,920
Electrician	1	1	0	2	11.10	53,280
Machinist	1	1	1	3	11.10	79,920
Utility Man	2	2	2	6	11.10	159,840
General Maintenance Crew	4	4	0	8	11.10	213,120
Foreman	1	1	2	4	11.10	106,560
	12	12	9	33		879,120
ADMINISTRATIVE & STAFF PERSONNEL						
SURFACE OPERATION:						
Manager	1	0	0	1	25.50	61,200
Assistant Manager	1	1	0	2	18.80	90,240
Engineer	2	0	0	2	16.50	79,200
Chemist, Lab & Quality Control	4	1	0	6	13.50	162,000
Inspector	2	2	0	4	13.50	129,600
RN & Safety Engineer	3	2	0	6	11.10	133,200
Guards & Custodian	3	3	2	9	10.50	201,600
Accountant, Clerical, Stenographer	6	3	2	11	10.50	277,200
Traffic Engineer	1	1	0	2	11.10	53,280
Warehouseman	2	1	1	4	10.50	100,800
	25	14	5	44		1,288,320
SUBSURFACE OPERATION:						
Inspector	1	1	0	2		53,280
Accountant, Clerical, Stenographer	2	2	0	4		91,200
Underground Supervision	1	1	0	2		53,280
	4	4	0	8		197,760

NOTE:

- Labor, cost includes 30% payroll additive and 8% overtime compensation.
- Number of significant figures shown in this table may exceed those justified by accuracy of the estimate.

APPENDIX F

HAZARDOUS WASTE STORAGE AT HERFA-NEURODE, GERMANY

Inspection Visit
of the
Hazardous Waste Storage
at
Herfa-Neurode, Germany
of
Kali & Salz

by
Charles H. Jacoby

for
Bechtel Subcontract (E.P.A.)

Kali und Salz Hazardous Waste Storage at Herfa-Neurode, Germany

Introduction

The storage of hazardous wastes in the Kali und Salz A.G. at Herfa-Neurode in West Germany is the first commercial attempt to store such wastes on a large scale. Mr. Charles H. Jacoby (formerly of International Salt Co.) in September of 1976, visited the operation and what follows is a summary of his observations.

The term waste storage is used by the Germans primarily because of the fact that for the first three years of placement, the waste remains the property of the producer. The material can be retrieved at Kali und Salz's option at the producer's expense if the material does not meet the specifications agreed upon by Kali und Salz and as shown in the form A and the letter of acceptance furnished to the producer after approval of the mining authorities.

After three years the waste becomes the property of Kali und Salz if no other terms are agreed upon in writing. During the five years of operation, there has been no occasion to retrieve material to return to a producer.

Geology

The underground depository at Herfa-Neurode is located in the southern part of the Permian Zechstein Basin. This extensive area of sedimentation, encompassing northwest Germany, the Netherlands and the larger part of Denmark, is well known for its voluminous production of potassium salts. The Zechstein evaporite sequence consists of four distinct cycles, each beginning with the deposition of a clastic, followed by one or more phases of sodiums, several levels of potassium salts and terminating with the deposition of a regressive halite or anhydrite. Figure 1 depicts the typical stratigraphy and thickness in the area.

The depository is located at a depth of about 700m in Zechstein 1 (Z1), a basin margin deposit. Figure 2 depicts a typical cross section of the "Thüringen" potash bed (K1Th). Above this level is a cover of rock salt approximately 170m in thickness which, in turn, bears layers of clay and argillaceous earth, a cavernous dolomite and an impervious clay. This forms an absolutely impervious seal to the variegated sandstone lying above. In the dolomite, waste brine from the potash refineries is disposed of. A 100m thick layer of rock salt immediately below the depository forms a barrier, prohibiting connections with the lower strata.

Stratigraphy and Thicknesses of German Zechstein in the Werra - Fulda - Area

Stratigraphy			Thicknesses (m) Werra	Thicknesses (m) Fulda
Zechstein 3 and 4	Z4t	Upper Zechsteinletten	10	10
	Ca3	Platy Dolomite	20	not typical
	Z3t	Lower Zechsteinletten	35	40
Zechstein 2	T2Na	Zwischensalinar Halite	5	10
	T2A	Zwischensalinar Anhydrite	10	–
	T2	Salt Clay	10	10
Zechstein 1	Na1γ	Upper Werra Halite	100	50
	K1H	Potashbed „HESSEN"	3	2,5
	Na1β	Middle Werra Halite	60	55
	K1Th	Potashbed THÜRINGEN"	3	2,2
	Na1α	Lower Werra Halite	100	90
	A1α	Lower Werra Anhydrite	5	3
	CaA1	Anhydritknotenschiefer	5	4
	Ca1	Zechstein Limestone	8	7
	T1	Copper Shale	0,3	0,3
	Z1C	Conglomerate	0-3	5

FIGURE 1 - TYPICAL STRATIGRAPHY OF PERMIAN ZECHSTEIN SEQUENCE

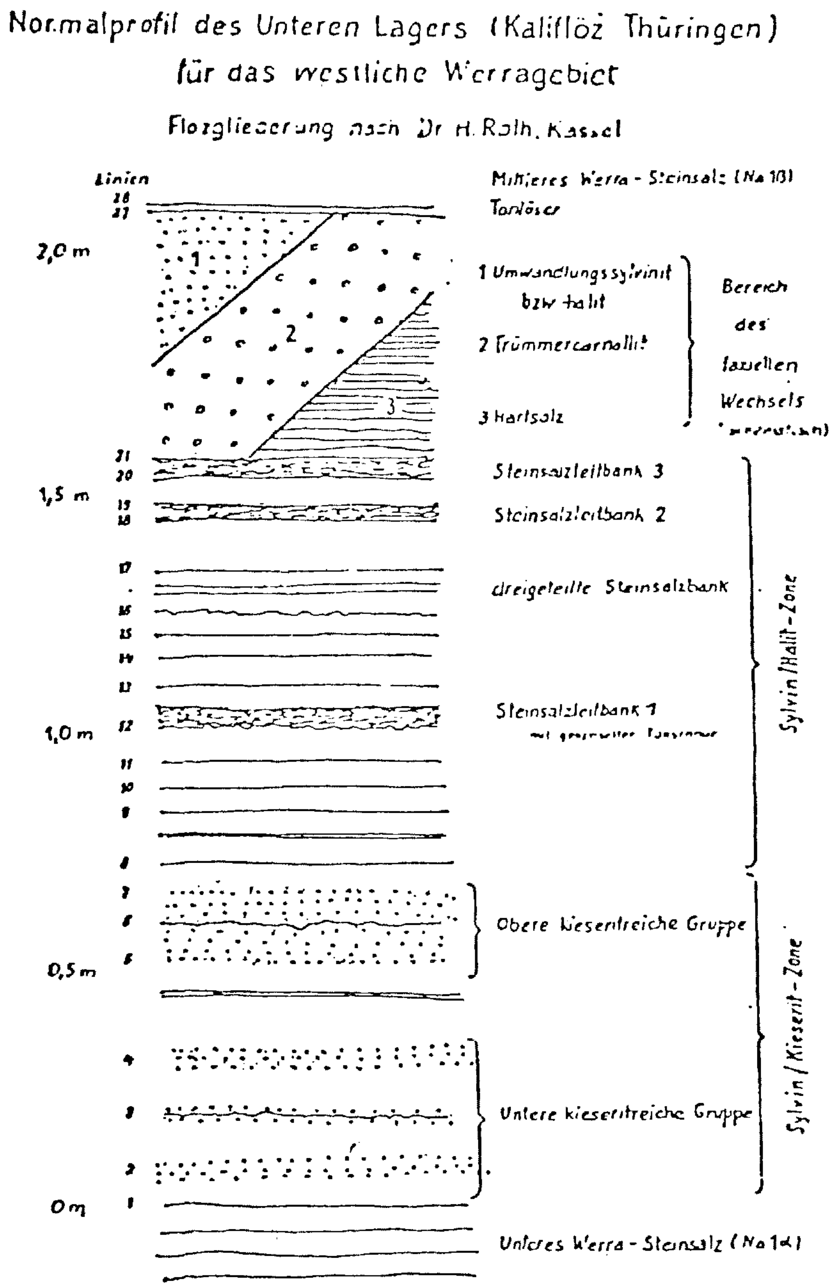

FIGURE 2 - CROSS SECTION OF "THÜRINGEN" POTASH BED

Figure 3 shows the location of the Herfa-Neurode facilities with respect to Bad Hersfeld, the nearest town of any size. The area has extensive mining operations as depicted in Figure 4. The storage facility is located (Figure 5) in the far northwest corner of the mine, some 4 km from the shaft area. Figure 6 details a section of the storage area.

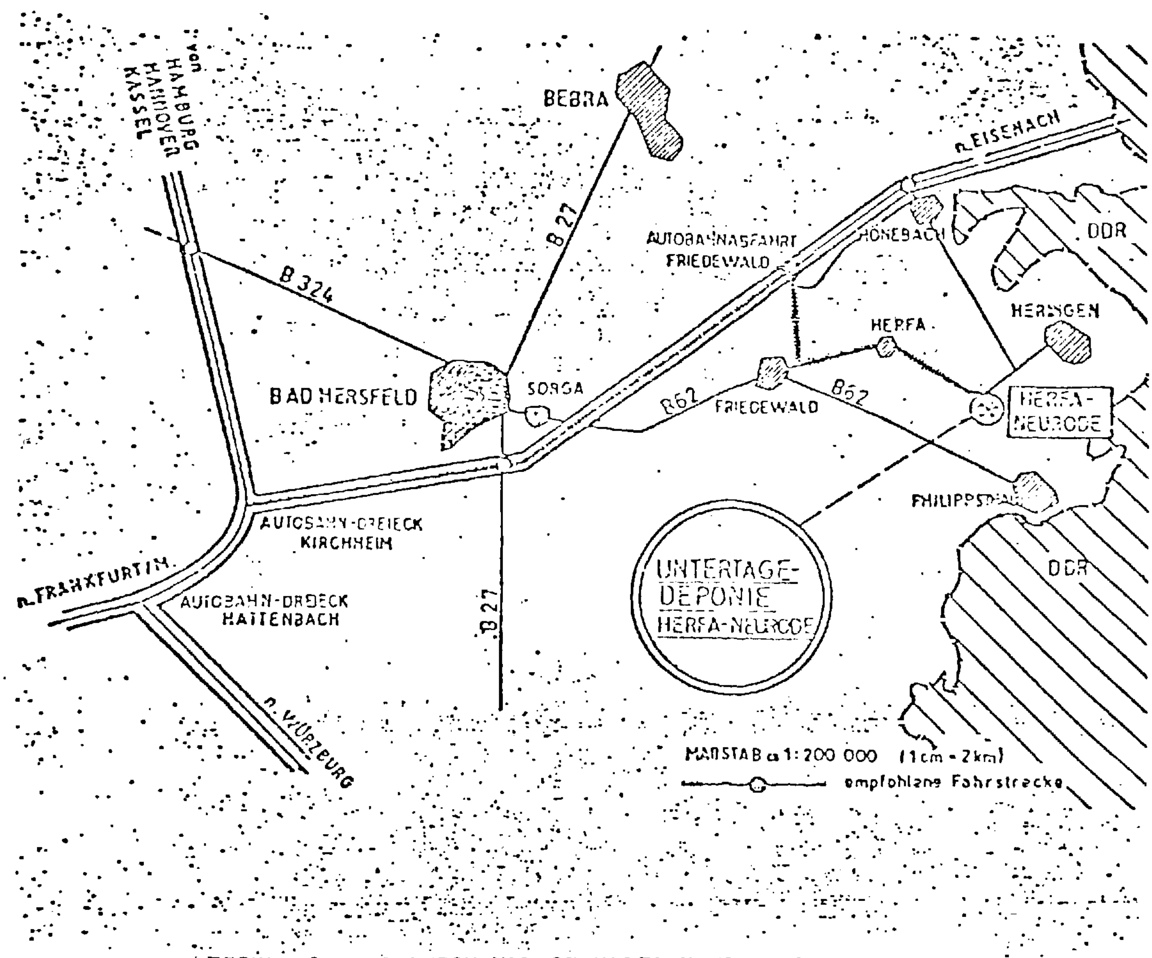

FIGURE 3 - LOCATION MAP OF HERFA-NEURODE FACILITIES

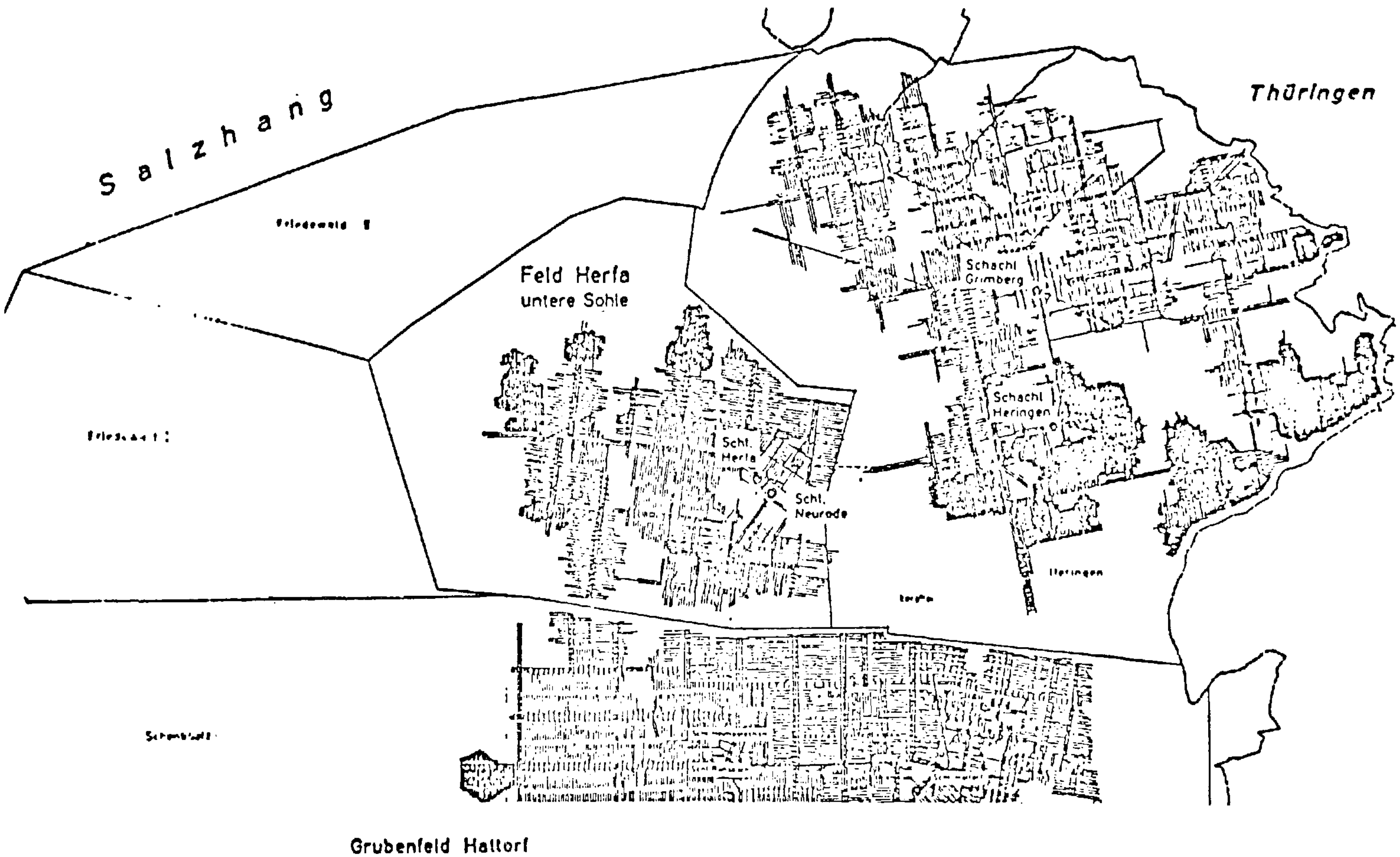

FIGURE 4 - MINING OPERATIONS IN THE HERFA-NEURODE AREA

0 1 2 3 4 5 km

Grubenfeldübersicht
Kaliwerk Wintershal

Grubenfeld Wintershall	1. Sohle
" Herfa	2. "
Teil " Hattorf	1. "

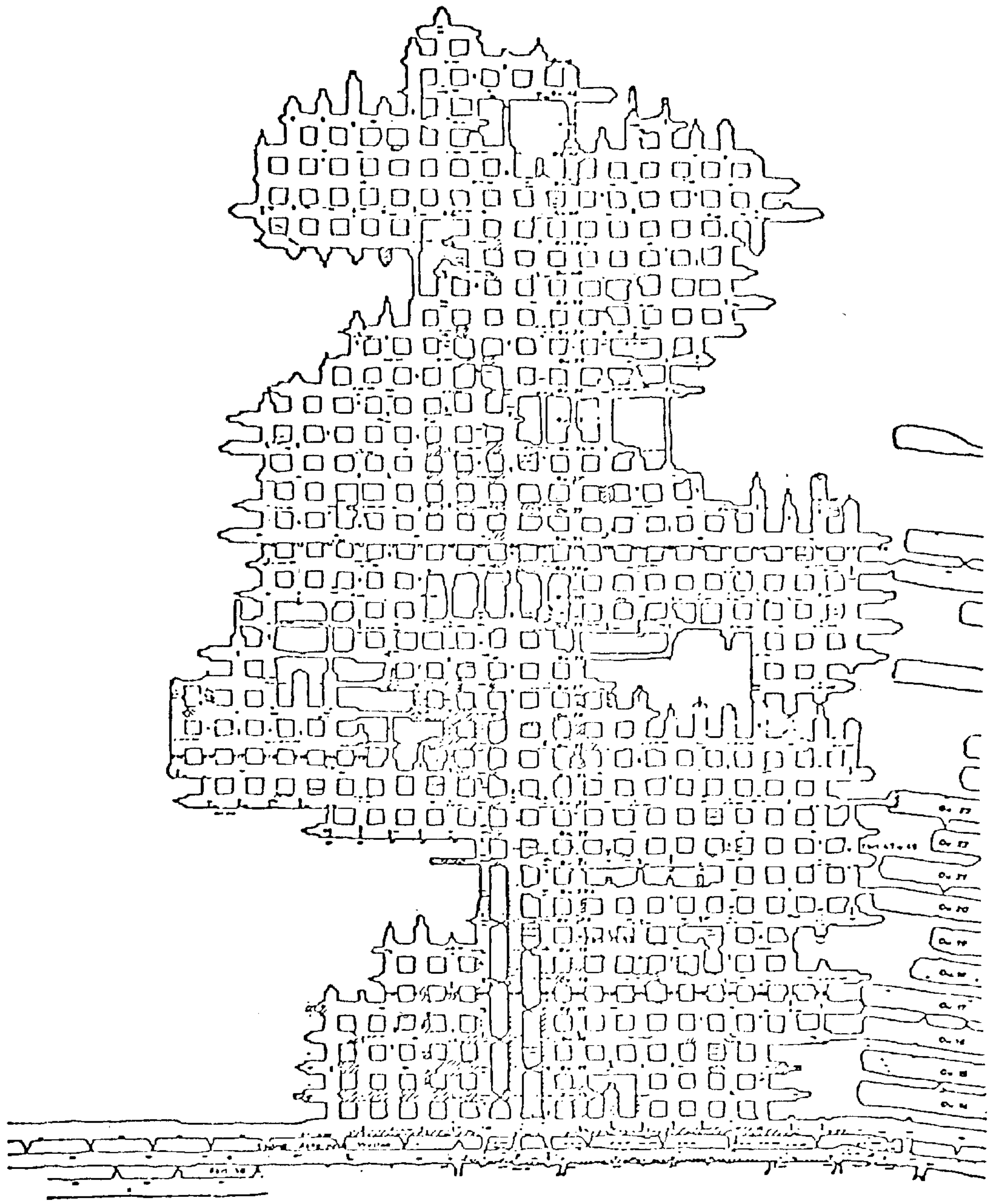

FIGURE 5 - MAP OF THE HERFA-NEURODE STORAGE AREA

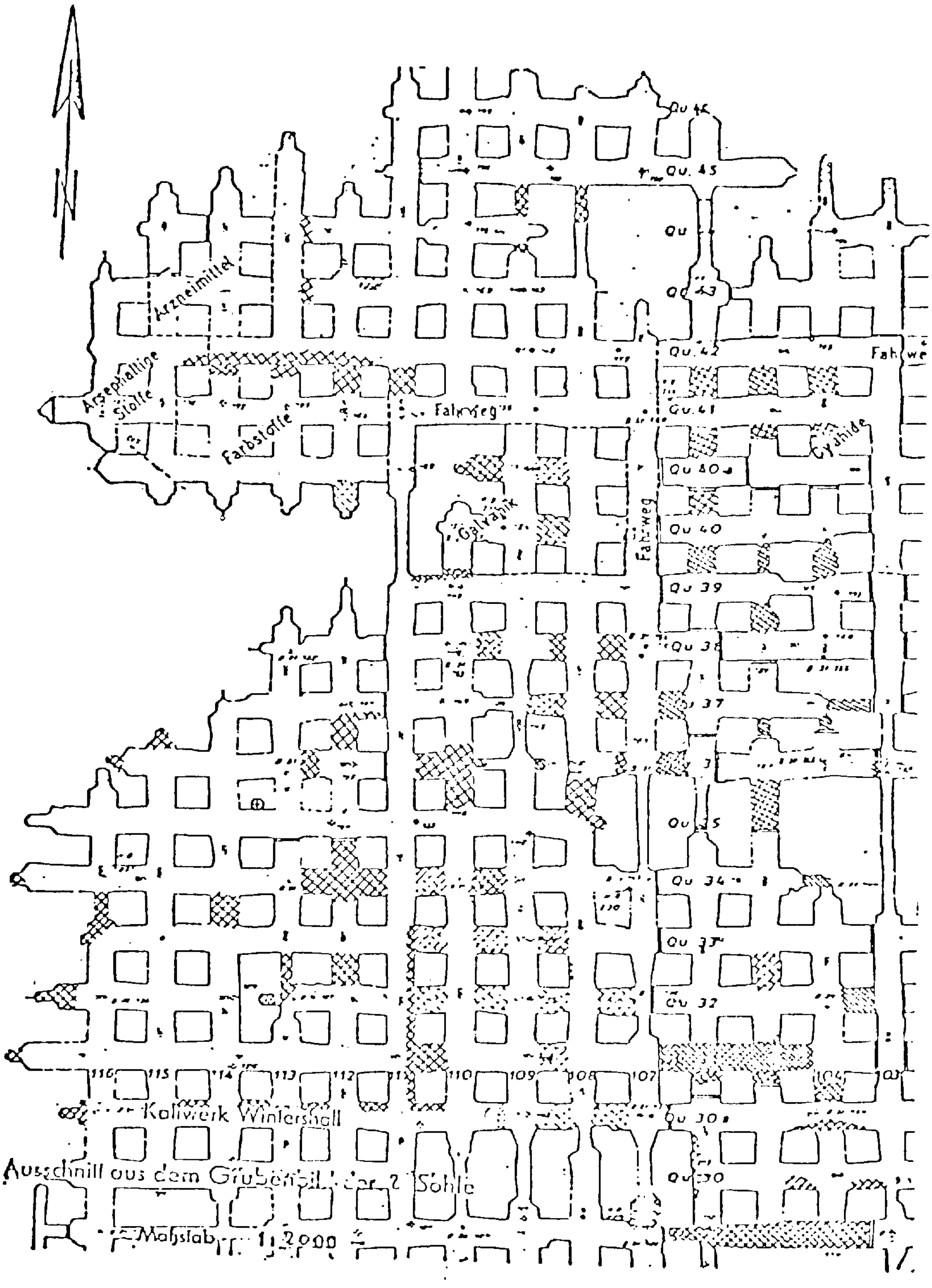

FIGURE 6 - DETAIL MAP OF STORAGE AREA

Previous Mining Operations

The mining of potash was the primary reason for the construction of Herfa-Neurode Mine. Reportedly, this mine was started in 1901 for the exploitation of the low grade potash ore which ran between 8 and 11% K_2O. A room and pillar system was used since trackless LHD equipment was introduced in 1969 where the room widths were 12-14 meters with basically square pillars of a dimension of 12-14 feet on each side, depending upon depth and rock mechanical properties of the potash mined. There was no evidence of undue pillar stressing. The height of the room openings is 2 to 3 meters which is a governing factor in the storage operations.

During recent years headings were driven as shown in Figure 7. This shows 3 contiguous 4 meter wide headings being driven in a V wedge. The three headings are four meters wide by 7 meters long. These headings or panels were drilled with auger drills and shot to form a wedge shaped pile of broken ore.

Generally speaking, the mine is somewhat similar to the Retsof Mine of International Salt Company. The section of potash bearing salt which is being mined is at a depth of 731 meters.

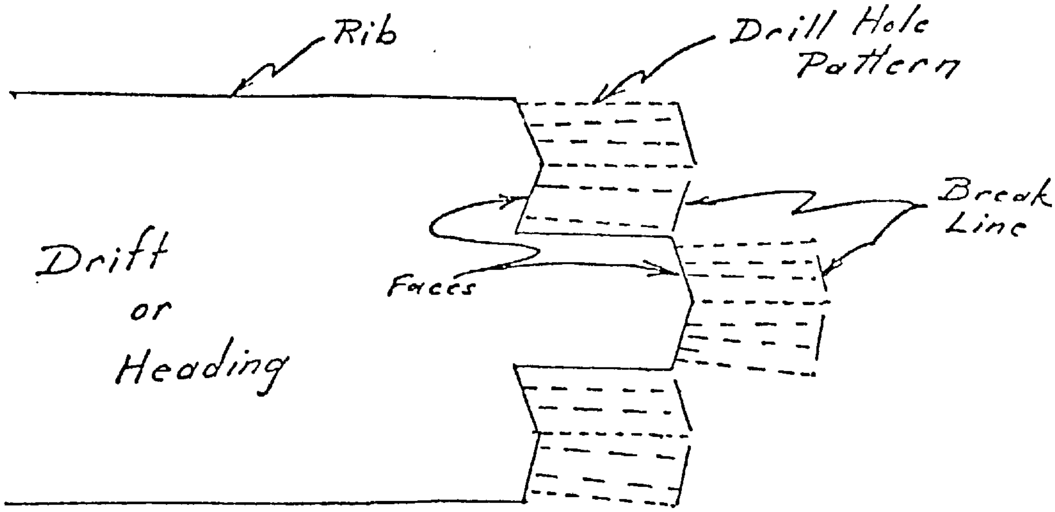

FIGURE 7 - MINING HEADING

Conversion

Reportedly, the principal cost of conversion lies in the clean up of waste salt and debris, scaling and renewed roof bolting to guarantee safe roof conditions. Prior to beginning this clean up, the roof is inspected for loose salt or slabs. These areas of possible roof problems are drilled with low angle holes; light charges of dynamite inserted into the holes, detonated and the possible dangerous material blasted down. Holes are drilled into the roof and 1m 20cm roof bolts installed. The 2cm bolts are shell type bolts anchored in salt on a 2 meter pattern. Plates over the bolt heads hold the roof in place.

Subsequent to the installation of the bolts, a payloader scoops up the waste salt and debris and dumps it into breaks or rooms which can not be used for storage. The governing factor in the use of a room for storage is the minimum permissible room height of 2 meters 30 centimeters. The floor has to be thoroughly prepared by grading and adding fine salt, which is in turn compacted by vibrators. The rooms are now ready for storage.

Method and Materials to be Stored

A master plan for the storage of materials has been developed for the more than 700 compounds handled. These compounds are separated into 19 different storage categories. Categories of storage vary from single compounds to multi-compound compartments.

There are three basic containers, normally 55 gallon steel drums, but occasionally smaller steel drums and plastic drums.

Brick walls are built at prescribed intervals in keeping with the type of wastes to be stored. When a predetermined volume of a given waste has been stored, a brick wall 12 meters long, 30 dm thick and 2½ meters high is built across the room. These brick walls are hand laid at a cost of 3,500 Deutsche Marks or $1520 per wall. Most of the walls have to be paid for by the producers, and this is agreed upon in the letter of acceptance, if the material they deliver makes this necessary to avoid bad odor or with respect to safety rules and ventilation requirements set by the mine or the mining authorities.

Special substances, such as outdated drugs, were put in an isolated fenced room under lock and key.

Ventilation

Two shafts service the storage area. One of these carry the downcast fresh air for ventilation while the other is up cast. The down cast air stream is split in the shaft so that 2,500 m^3/min. goes to the storage operation while the remainder of the flow is diverted to the active mining areas. This section of down cast area shaft is the only mutual contact between the material to be stored and the areas in which mining is currently being conducted.

No water was observed either in the mine or in the man shaft. Where the two shafts penetrated the aquifer overlying the Zechstein salt formations, steel tubbing was used. This steel tubbing has been caulked by using lead in the joints.

Air entering the mine from the down cast shaft travels along the 4.5 kilometer haulageway leading to the storage area. This same haulageway is used for vehicular traffic carrying waste to storage. Exhaust air is carried in an isolated return air system and discharged to the up cast air shaft. Air from this shaft is discharged directly to the atmosphere with no prior filtering or scrubbing.

Storage Charges & Tonnages

Storage charges are based on metric tons with the current cost being 122.80 DM (2.3 dm = $1.00). The density of the material being stored is usually not taken into consideration. The greatest weight of a drum filled with dry bulk waste is 500 kg. Normally, a skip load consists of 8 tons. Thus, in order to meet their standard hoist of 200-300 tons per shift (1 shift per day) they must lower an average of 40 tons per hour.

During the last four years of operation approximately 100,000 tons of waste have been stored. In 1975, about 40,000 tons of waste were disposed of at Herfa-Neurode. The projected tonnage for this year is between 36 to 38,000. It is estimated that the current storage rate requires 150,000 m^3 of space/year. Reportedly, the mining operations will create some 2 x 10^6 m^2/yr. from a tonnage of 25,000 tons daily.

Summary & Conclusions

With the exception of lowering the waste into the mine through the fresh air down cast air shaft and the materials transport to the storage area in the fresh air haulageway, we were in basic agreement with the German operation.

The Germans were prepared for spillage clean up; for example, if steel drums or other containers had been punctured by the fork lift or dropped from the truck.

Of particular significance was their system of scheduling and coding waste shipments. The waste producer makes application for the storage of their waste by chemical composition and volume. After permission is granted, the tentative date of shipment is stipulated and a 24 hour shipping notice is given by Kali und Salz. When the shipment is made, copies of the "Waste-Waybill" (Abfallbegleitschein) are given to the respective authorities so that transport control is possible. Upon receipt of the shipment, a maximum of 24 hours of surface "shed" storage is provided. The responsibility for the waste is assumed by Kali und Salz at the time the material is unloaded from the trucks after examination of the load and waste-waybill.

Material to be lowered into the mine is taken directly from the surface transport vehicle or from the shed storage and placed in the mine cage ready for lowering into the mine. This skip has a stipulated load capacity of 8 tons (metric).

All drums are delivered on one-way pallet and strapped with a steel band to avoid dislocation on the pallets during the transport and handling with fork lifts. Two pallets are stacked on top of each other. This standard configuration varies with the density of the material being stored. Drums are coded in keeping with a master map and ledger book. Upon arrival underground, the code numbers are recorded in a separate ledger and placed on another map in the exact spot where the material is to be stored.

A full emergency medical facility to cover all eventualities has been set up near the bottom of the shaft. This facility is equipped with showers, medicines and baskets. Adjacent to this facility is a "double" change room, together with a lunch room. Elaborate precautions have been taken with respect to both lunch room sanitation and contamination.

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Untertage-Deponie Herfa-Neurode

Sehr geehrte Herren!

Wir übersenden Ihnen die "Allgemeinen Geschäftsbedingungen" und das "Formblatt A" unserer Untertage-Deponie Herfa-Neurode.

Die Untertage-Deponie Herfa-Neurode ist insbesondere für die Ablagerung von Abfallstoffen geeignet, die anderweitig nicht umweltunschädlich beseitigt werden können.

Im Interesse der Sicherheit des Betriebes unter Tage unterliegt sie jedoch folgenden Beschränkungen:

1. Die Abfallstoffe dürfen in den praktisch geschlossenen Räumen unter Tage keine zündfähigen, explosiven oder toxischen Gas - Luft - Gemische bilden.
2. Flüssige Abfallstoffe können nicht abgelagert werden. Solche Abfallstoffe müssen mit geeigneten Mitteln in absolut stichfeste Form überführt werden, so daß keine freien Flüssigkeiten austreten können.

Bei Abfallstoffen, die zunächst infolge dieser Beschränkungen nicht angenommen werden können und deren anderweitige umweltunschädliche Beseitigung technisch und wirtschaftlich nicht gegeben ist, lassen sich in vielen Fällen durch gemeinsam zu erarbeitende Verfahren (Konditionierung, besondere Verpackung, Abmauerung untertage usw.) die Voraussetzungen für die sichere Ablagerung in der Untertage-Deponie schaffen.

Mit der Übersendung des "Formblatts A" (in zweifacher Ausfertigung) an die Kali + Salz AG., Abt. B 3, 35 Kassel, Postfach 102029 erkennt der Beseitigungspflichtige die "Allgemeinen Geschäftsbedingungen" an. Darüber hinaus gelten die in der schriftlichen Annahmebestätigung der Untertage-Deponie ggf. festgelegten vereinbarten besonderen Bedingungen.

Genehmigungsverfahren

Der Beseitigungspflichtige erhält nach Prüfung des betreffenden Abfallstoffes und der Genehmigung durch das Bergamt Bad Hersfeld von der Untertage-Deponie Herfa-Neurode die schriftliche Annahmebestätigung, der eine Kopie des mit dem Genehmigungsvermerk des Bergamtes versehenen "Formblatts A" beigefügt ist. Annahmebestätigung, bergbehördliche Genehmigung und Code-Bezeichnung gelten für die wiederholte Anlieferung des gleichen Abfallstoffes (s.§§ 13 und 11 der "Allgemeinen Geschäftsbedingungen"). In der Annahmebestätigung und auf dem "Formblatt A" ist die Code-Bezeichnung angegeben, mit der die Behälter, in denen der betreffende Abfallstoff angeliefert wird, deutlich lesbar und dauerhaft zu beschriften sind.

Mit diesen Unterlagen kann der Beseitigungspflichtige dann gemäß den Verordnungen der Bundesregierung vom 29. 7. 74 zu den §§ 11, 12 und 13 des Abfallgesetzes bei seiner zuständigen Behörde die Transportgenehmigung beantragen. Nach Erhalt der Transportgenehmigung vereinbart der Beseitigungspflichtige mit dem Betrieb der Untertage-Deponie Herfa-Neurode die verbindlichen Anlieferungstermine.

Auf den Begleitscheinen nach der Abfallnachweisverordnung vom 29. 7. 74, § 2 Abs. 1 müssen zusätzlich Code-Nummer und Zahl der angelieferten Behälter angegeben werden.

Anlieferung

Die Anlieferung kann nur mit LKW erfolgen. Die Behälter, in der Regel 200-Liter-Stahlblechfässer mit Spannringverschluß, müssen mechanisch einwandfrei, dicht verschlossen und dürfen äußerlich nicht verunreinigt sein.

Die Behälter sind auf Paletten (Abmaße bis zu 1200 x 1200) anzuliefern und durch ein horizontales Stahlband so zu umschlingen, daß ein Verrutschen beim Transport und beim Be- und Entladen sicher verhindert wird. Einweg-Paletten können bei bestimmten Stoffen vorgeschrieben werden. Auf einer Palette dürfen nur Abfallstoffe gleicher Art und Behälter gleicher Größe angeliefert werden.

Mit freundlichem Gruß und Glückauf!

KALI UND SALZ AKTIENGESELLSCHAFT

i.V. von der Ehe

(Dr. Johnsson) (i.V. von der Ehe)

der
Kali und Salz AG

3500 Kassel 1, Friedrich-Ebert-Straße 160
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Betrieb Herfa-Neurode
6432 Heringen (Werra), Werk Wintershall
Telefon: (06624) 811
Fernschreiber: 493383

Allgemeine Geschäftsbedingungen (1. 2. 1975)

§ 1

Die Kali und Salz Aktiengesellschaft – im folgenden „K + S" genannt – übernimmt die in Formblatt A beschriebenen Abfallstoffe des Beseitigungspflichtigen – im folgenden „Firma" genannt – zur Ablagerung in ihrer Untertage-Deponie nach Maßgabe ihrer schriftlichen Annahmebestätigung sowie dieser Geschäftsbedingungen.

§ 2

(1) Die Firma vereinbart mit K + S, Betriebsabteilung Herfa-Neurode, die näheren Einzelheiten über den Umfang und die zeitliche Folge der Teillieferungen. Dabei wird die Firma bemüht sein, K + S über voraussichtliche Mengen an Abfallstoffen zu unterrichten, die kontinuierlich anfallen und in gleichbleibenden Teilmengen bei K + S angeliefert werden sollen.

(2) Nicht kontinuierlich anfallende Abfallstoffe werden mindestens 14 Tage vor dem gewünschten Anlieferungstag von der Firma bei K + S angemeldet. Der endgültige Anlieferungszeitpunkt wird daraufhin vereinbart.

§ 3

(1) Die Firma zahlt an K + S je Tonne abgelagerten Abfallstoff einen Grundpreis von DM 117,–. Je nach Art und Menge des abzulagernden Abfallstoffes können Zuschläge oder Abschläge zu diesem Grundpreis für die jeweilige Lieferung vereinbart werden.

(2) Die Vergütung für jede Lieferung wird 14 Tage nach Rechnungseingang fällig. Bei fortlaufenden Lieferungen erfolgt die Rechnungslegung am 15. und 30. eines jeden Monats.

(3) Der in Absatz 1 genannte Grundpreis enthält zu 70 % an Personalkosten gebundene Aufwendungen. Bei einer Änderung der Personalkosten ändert sich auch mit sofortiger Wirkung im gleichen Verhältnis der an Personalkosten gebundene Teil des Grundpreises. Maßgebend für eine Änderung ist die Änderung des Lohntarifvertrages zwischen der Industriegewerkschaft Bergbau und Energie, Bochum, und dem Kaliverein e. V., Hannover, vom 8. 7. 1974

Der Grundpreis enthält zu 30 % Abschreibung und Verzinsung bereitgestellter Geräte. Ändert sich der Index der Erzeugerpreise der Investitionsgüter-Industrie (Grundlage: Veröffentlichung des Statistischen Bundesamtes, Wiesbaden, Fachserie M, Reihe 3, unter „Index der Erzeugerpreise industrieller Produkte und Investitionsgüter", Ausgangszahl: Index für das Jahr 1973), dann ändert sich der an Abschreibung und Verzinsung gebundene Teil des Grundpreises im gleichen Verhältnis, und zwar mit Wirkung des der Veröffentlichung folgenden Monats.

§ 4

Die Firma führt die Anlieferung des Abfallstoffes zur Schachtanlage Herfa-Neurode, Herfagrund, bis zum Zechenplatz in eigener Verantwortung, auf eigene Gefahr und auf eigene Kosten durch. Die Gefahr geht auf K + S über bei der Abladung.

§ 5

(1) Die Firma hat die Abfallstoffe in einer den jeweils geltenden gesetzlichen Bestimmungen und behördlichen Anordnungen entsprechenden Verpackung anzuliefern. Darüber hinaus gelten die mit K + S vereinbarten und in der schriftlichen Annahmebestätigung festgelegten Anforderungen an Art und Beschaffenheit der Verpackung.

(2) Die Firma gewährleistet die Eigenschaften der Abfallstoffe gemäß den nach Formblatt A gemachten Angaben nach Maßgabe von § 9 K + S behält sich vor, die angelieferten Abfallstoffe hinsichtlich der Übereinstimmung mit den Angaben des Formblattes A zu überprüfen. Werden wesentliche Abweichungen festgestellt, trägt die Kosten der Untersuchung die Firma.

(3) K + S muß verlangen, – sofern das Bergamt Hersfeld als zuständige Aufsichtsbehörde die von den Laboratorien des Beseitigungspflichtigen gemachten Angaben nicht anerkennt –, daß der Beseitigungspflichtige Prüfatteste anerkannter Prüfstellen erstellen läßt, die zu den Angaben in Formblatt A Stellung nehmen und Aussagen über die Eignung der Abfallstoffe hinsichtlich der Ablagerung unter den Bedingungen der Untertage-Deponie machen.

§ 6

(1) Die Ablagerung der Abfallstoffe bedarf einer genauen Überwachung durch K + S, unter anderem auch hinsichtlich der abzulagernden Mengen.

(2) Zu diesem Zweck müssen in den Warenbegleitpapieren die Anzahl der Behälter und das Bruttogewicht der Ladung durch eine Wiegekarte belegt werden. Vor der Abladung auf dem Zechenplatz der Schachtanlage Herfa-Neurode, Herfagrund, wird die Übereinstimmung der Warenbegleitpapiere mit der Ladung durch Zählung und Wägung der Ladung überprüft. Wird keine mengen- oder gewichtsmäßige Übereinstimmung festgestellt, wird K + S die Firma verständigen. Für die Aufklärung der fehlenden Übereinstimmung hat die Firma zu sorgen. Bis zur Aufklärung etwaiger Unstimmigkeiten kann K + S die Annahme verweigern.

§ 7

Die Entladung sowie alle weiteren Maßnahmen zur Durchführung werden von K + S schnellstmöglich vorgenommen.

§ 8

(1) Die abgelagerten Abfallstoffe gehen – wenn nichts anderes gesondert schriftlich vereinbart wird – drei Jahre nach Anlieferung in das Eigentum von K + S über.
(2) Die Firma kann, solange sie Eigentümerin der abgelagerten Abfallstoffe ist, Rückgabe dieser Stoffe verlangen; sie hat jedoch die durch die Auslagerung entstehenden Kosten zu tragen.

§ 9

(1) Unbeschadet der gesetzlichen Bestimmungen haftet die Firma für jeden Schaden, der K + S dadurch entsteht, daß der zur Ablagerung angelieferte Abfallstoff

a) nicht den Angaben des Formblattes A entspricht,
b) nicht gemäß den mit K + S getroffenen Vereinbarungen verpackt ist.

(2) Die Firma stellt K + S von allen Schadenersatzansprüchen Dritter frei, die auf den in Abs. 1 a bis b genannten Gründen beruhen.

§ 10

(1) K + S haftet für schuldhaftes Handeln, jedoch begrenzt auf die Höhe der Deckungssumme der von ihr abgeschlossenen Haftpflichtversicherung. Diese beträgt 2 000 000,– DM für jeden Schadensfall.

(2) K + S stellt die Firma von allen Ansprüchen Dritter frei, die auf schuldhaftem Handeln von K + S (oder ihren Erfüllungs- oder Verrichtungsgehilfen) bei der Erfüllung dieses Vertrages beruhen.

§ 11

(1) K + S ist über die gesetzlichen Bestimmungen über den Fall des § 8 dieses Vertrages hinaus von ihrer Ablagerungsverpflichtung gemäß § 1 befreit, wenn
a) die Firma nicht fristgemäß den nach § 2 vereinbarten Meldepflichten nachkommt,
b) einer der in § 9 Abs. 1 a–b genannten Gründe vorliegt,
c) die Ablagerung durch Gesetz oder durch behördliche Anordnung untersagt wird,
d) K + S beweist, daß die Ablagerung aus betrieblichen, von K + S nicht verschuldeten Gründen unmöglich oder unzumutbar ist.

(2) Die Befreiung von der Ablagerungsverpflichtung gilt nur für die jeweiligen Teilmengen des abzulagernden Abfallstoffes, für die einer der in Abs. 1 genannten Gründe eingetreten ist.

§ 12

(1) Die Pflicht von K + S zur Verwahrung der abgelagerten Abfallstoffe besteht solange, bis die Abfallstoffe in das Eigentum von K + S übergehen.

(2) K + S kann die Rücknahme abgelagerter Abfallstoffe nur dann verlangen, wenn die Abfallstoffe nicht dem Formblatt A, oder den hinsichtlich der Verpackung getroffenen Vereinbarungen entsprechen, oder wenn ein anderer wichtiger Grund vorliegt, der nicht in die Risikosphäre von K + S fällt.
Mit Eigentumsübergang erlischt jede Rücknahmeverpflichtung.

(3) Übt K + S einen Rücknahmeanspruch gemäß Abs. 2 aus einem Grunde aus, den die Firma zu vertreten hat, so hat die Firma alle sich daraus ergebenden Kosten zu tragen.

(4) Ein Anspruch auf Erstattung der gezahlten Vergütungen im Falle der Ausübung des Rücknahmeanspruchs gemäß Abs. 2 besteht nicht.

§ 13

Beide Vertragspartner können den Vertrag jeweils zum Jahresende mit einjähriger Frist kündigen. Die Kündigung hat keine Wirkung für die während der Vertragsdauer abgelagerten Mengen.

§ 14

Das Formblatt A ist wesentlicher Bestandteil des Vertrages.

§ 15

Änderungen, Ergänzungen und die Kündigung des Vertrages bedürfen der Schriftform.

§ 16

Allgemeiner Gerichtsstand ist Kassel.

der

Kali und Salz AG

Formblatt A

UNTERTAGE-DEPONIE HERFA-NEURODE

der

Kali und Salz AG

3500 Kassel 1, Friedrich-Ebert-Straße 160
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Betrieb Herfa-Neurode
6432 Heringen (Werra), Werk Wintershall
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Fernschreiber: 493383

Dieses Formblatt A ist vom Beseitigungspflichtigen in doppelter Ausfertigung an Kali und Salz AG, B 3, 35 Kassel 1, Postfach 102029, zu übersenden. Die schriftliche Annahmebestätigung erfolgt nach Überprüfung der Angaben.

1. Bezeichnung des Abfallstoffes, Menge, Art der Verpackung (ggf. Stoffkennzeichnung nach ADR bzw. EVO):

2. Produktionsherkunft:

3. Codebezeichnung (Mit K+S zu vereinbaren):

4. Wie wurde der Abfallstoff nach seinem Anfallen beim Beseitigungspflichtigen behandelt und gelagert? (dazu ggf. Angabe werksinterner Vorschriften, behördlicher Bestimmungen usw.)

5. Chemische Bezeichnung der Einzelkomponenten	Anteile in % Ø	min.	max.
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			

6. Beschaffenheit (bei 30 °C):

flüssig ☐ fest erstarrte Schmelze ☐ schlammig / stichfest ☐
zähflüssig/teigig ☐ fest-körnig ☐ schlammig / flüssig ☐
fest-pulverig ☐

7. Wasser- bzw. Flüssigkeitsgehalt (Gewichts-%) ________
Aus welchen Stoffen bestehen die Flüssigkeiten?

8. Schmelzpunkt (°C) ________
9. Siedepunkt (°C) ________
10. Flammpunkt (°C) ________

11. PH-Wert ________
12. Gasdruck bei 20 °C (Torr) ________
bei 50 °C (Torr) ________

13. Welche Gase kann der Abfallstoff durch eventuelle Nachreaktionen unter den Ablagerungsbedingungen entwickeln?

a) Wenn er im Anlieferungsbehälter eingeschlossen bleibt:

b) Wenn er mit Luft in Berührung kommt:

c) Wenn er mit dem anstehenden Salz in Berührung kommt:

d) Bei welchen Temperaturen treten Zersetzungen, Ausgasungen, spontane Zersetzungen oder Explosionen auf?

Welche Gasgemische können bei den betreffenden Temperaturen entstehen?

Hdr. 6.78 VN 3341

14. Angaben über die toxikologischen Eigenschaften des Abfallstoffes (ggf. ausführliche Angaben gesondert beifügen)

15. Bei Transportschäden, insbesondere Bränden:

a) Geeignete Löschmittel, unzulässige Löschmittel

b) Atemschutz

c) Angaben über Vorschriften (behördliche und/oder werksinterne) zur Behandlung von Personen, die mit dem Abfallstoff direkt in Berührung gekommen sind (Schleimhäute, Haut) oder die bei Bränden den entstehenden Gasen ausgesetzt waren (ggf. ausführliche Angaben gesondert beifügen)

Angaben zu den Bedingungen unter Tage der Deponie Herfa-Neurode

Die Abfallstoffe werden in leergeförderten Abbauen von etwa 2,5 - 3,5 m Höhe abgelagert. Temperatur: 25 - 30 °C, relative Luftfeuchtigkeit: max. 45%. Gehalte der Grubenwetter an Abgasen: CO: ~ 0,001 (Vol.%), CO_2: ~ 0,1 (Vol.%), NO_2: ~ 2,5 (mg/m³).

Das anstehende Salz hat im Mittel folgende Zusammensetzung:

$MgSO_4 \cdot H_2O$ (Kieserit):	10 - 20%	$KCl \cdot MgCl_2 \cdot 6H_2O$ (Carnallit):	5 - 10%	Unlösliches (Ton usw.):	1 - 1,5%
KCl (Sylvin):	10 - 15%	NaCl (Steinsalz):	60 - 65%		

Erklärung

Wir versichern, daß die im Formblatt A zum Vertrag mit der K+S gemachten Angaben zutreffen.

Die zur Ablagerung in die Untertage-Deponie Herfa-Neurode anzuliefernden Abfallstoffe entsprechen den aufgeführten Deklarationen. Das mit der Deklaration und dem Transport beauftragte Personal ist von uns gegen Unterschriftsbestätigung darauf hingewiesen worden, daß

a) nur genau definierte Abfallstoffe entsprechend den Angaben dieses Formblattes A zur Abfuhr bereitgestellt,

b) keine anderen als die im Formblatt A definierten Abfallstoffe zur Untertage-Deponie Herfa-Neurode angeliefert werden dürfen.

Verantwortlich	Name	Telefon	Name des Stellvertreters
a) Für die analytischen Angaben:			
b) Für gewissenhafte Deklaration:			
c) Für Verladung und Transport:			

Anschrift der Firma : Datum: Rechtsverbindliche Unterschrift der Firma

Raum für Behördenvermerke:

Kali und Salz AG K+S

UNTERTAGE-DEPONIE HERFA-NEURODE (5)

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Hauptverwaltung

Ihre Zeichen	Ihre Nachricht vom	Unsere Zeichen	Telefon-Durchwahl	Kassel, Friedrich-Ebert-Straße 160 (August-Rosterg-Haus)
		B3-Jo/hei	(0561) 301 395	15. Januar 1976

Preise für die Ablagerung von Abfallstoffen für das Jahr 1976

Wir freuen uns, Ihnen mitteilen zu können, daß wir für das Jahr 1976 die Preise für die Ablagerung von Abfallstoffen in der Untertage-Deponie Herfa-Neurode nicht erhöhen müssen. Für 1976 gilt also der seit 1. 2. 1975 berechnete Preis von 117,-- DM/t frei Herfa-Neurode.

Durch die konsequente Ausschöpfung noch vorhandener Rationalisierungsmöglichkeiten ist es uns gelungen, die im Kali- und Steinsalzbergbau am 1. 9. 1975 erfolgte Erhöhung der Löhne und Gehälter von 6,8 % und den Einfluß des auch 1975 eingetretenen Anstiegs des Index für die Erzeugerpreise der Investitionsgüter-Industrie voll aufzufangen.

Zu diesem Erfolg hat Ihre für uns unerläßliche Mitarbeit im erheblichen Umfang mit beigetragen; denn die im Jahre 1975 erfolgte vollständige Umstellung der Anlieferung und Ablagerung auf Einwegpaletten und weitere Verbesserungen bei der Verpackung und Anlieferung der Abfallstoffe waren die Voraussetzungen, die es uns ermöglicht haben, den Ablagerungspreis konstant zu halten.

Die Kali + Salz AG wird auch in Zukunft bestrebt sein, in enger Zusammenarbeit mit den Beseitigungspflichtigen das Dienstleistungsangebot für die sichere Beseitigung von Abfallstoffen, die anderweitig nicht umweltfreundlich und wirtschaftlicher beseitigt werden können, weiter zu entwickeln.

Glückauf

KALI UND SALZ AKTIENGESELLSCHAFT

(Heim) (Johnsson)

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-215	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE COST ASSESSMENT FOR THE EMPLACEMENT OF HAZARDOUS MATERIALS IN A SALT MINE		5. REPORT DATE November 1977 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B.T. Kown, R.A. Stenzel, J.A. Hepper, J.D. Ruby, R.T. Milligan		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bechtel Corporation San Francisco, California 94119		10. PROGRAM ELEMENT NO. 1DB064 SOS2 Task 4 11. CONTRACT/GRANT NO. 68-03-2430
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final July 76 thru May 77 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Robert E. Landreth, P.O. Phone No. 513/684-7871

16. ABSTRACT

This report presents the results of an economic evaluation of the storage of nonradioactive hazardous wastes in underground mine openings. This study is a part of a continuous effort to find a new and better method of disposing or storing hazardous wastes in an environmentally acceptable manner. The technical assessment of the hazardous waste storage in underground mine openings performed in an earlier study (EPA-600/2-75-040) indicated that long-term storage of hazardous wastes in a room and pillar type salt mine was an environmentally acceptable method provided that certain precautions are taken. This study is performed to develop the cost data associated with the storage of hazardous wastes in a typical room and pillar type salt mine, including the capital and operating costs. The intent of the study is to reveal economic sensitivity of various parameters involved in the underground storage of hazardous wastes. In order to develop the cost data, this study also involved characterization of the wastes and conceptual design of the waste receiving, treatment, containerization, and storage facilities.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste disposal, sludge disposal, stabilization, waste treatment, encapsulating, hazardous materials, economic analysis, operating costs, capitalized costs	Solid waste management, hazardous waste management, fixation	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 199
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978— 757-140/6623