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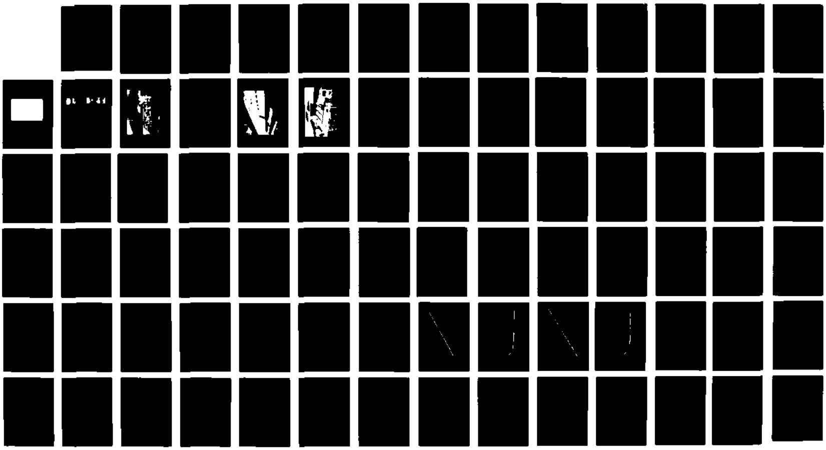

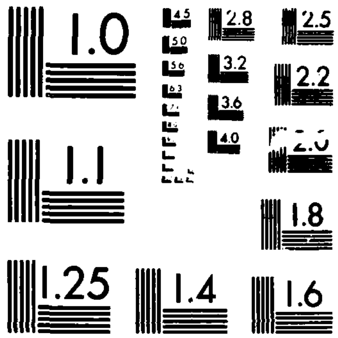
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Report No. AMXTH-TE-CR 86085

Installation Restoration General Environmental Technology Development Contract DAAK11-85-C-0007

AD A171 521

TECHNICAL REPORT

Economic Evaluation of Low Temperature Thermal Stripping of Volatile Organic Compounds From Soil

AD-A171 521

August 1986

Distribution Unlimited; Approved for Public Release

Prepared for:
U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
Aberdeen Proving Ground (Edgewood Area), Maryland 21010

WESTON MANAGERS DESIGNERS/CONSULTANTS

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REPORT NO. AMXTH-TE-CR 86085

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Operating Costs

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a comprehensive study that evaluates the economics of four separate low temperature thermal stripping (LTTS) system sizes and two separate system configurations (i.e., with and without flue gas scrubbing) for application at three separate size sites. LTTS system capital and operating costs are presented in total dollars and unit cost (i.e., $/ton).

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(continued)

FIGURES

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TABLES

1. EXECUTIVE SUMMARY

1.1 Background. Under Task Order 11 of Contract DAAK 11-82-C-0017, a field demonstration project was conducted at Letterkenny Army Depot in the fall of 1985. This pilot testing project demonstrated that the low temperature thermal stripping process could successfully remove volatile organic compounds (VOC's) from soils. The results of this prior investigation are presented in Report No. AMXTH-TE-CR-86074, "Task 11. Pilot Investigation of Low Temperature Thermal Stripping of Volatile Organic Compounds (VOC's) from Soil," dated June 1986.

1.2 Objective. This report presents an economic analysis of:

1. Four Separate System Sizes

- System A - One thermal processor consisting of two 24-inch diameter and two 24-foot long Holo-Flite® screws.
- System B - One thermal processor consisting of four 24-inch diameter and four 24-foot long Holo-Flite® screws.
- System C - Two thermal processors as described for System B arranged in series.
- System D - Four thermal processors consisting of two parallel trains with two thermal processors each as described for System C.

2. Two Separate System Configurations

- Option 1 - Without flue gas scrubbing.
- Option 2 - With flue gas scrubbing.

3. Three Separate Size Sites

- Site 1 - With 1,000 tons of contaminated soil.
- Site 2 - With 10,000 tons of contaminated soil.
- Site 3 - With 100,000 tons of contaminated soil.

The objective of this report is to recommend which size and configuration of equipment (if any) should be considered for development of technical data packages for full-scale implementation at U.S. military installations. A secondary objective of this report is to recommend additional studies or investigations that may be required.

1.3 Summary of major findings and recommendations. System B is the most economic system evaluated for sites with 15,000 to 80,000 tons of soil to be processed. The estimated incremental total project costs for System B ranged from $160/ton to $74/ton, respectively, for the above size sites. With a flue gas scrubber, these estimated costs increased to $184/ton to $87/ton, respectively.

Recommendations are summarized below:

1. A Technical Data Package (performance oriented) should be developed for System B. This is the most cost-effective system for the range of sites from 15,000 to 80,000 tons. The Technical Data Package should include flue gas scrubbing (if required) based on soil characteristics.
2. A survey/literature search of sites targeted for remedial action under the Installation Restoration Program should be performed to determine if technical data packages for smaller (System A) or larger (System C) systems are justified.
3. To further refine operating costs, testing should be performed on a wide variety of uncontaminated soil types and moisture contents to establish an accurate data base for heat transfer coefficients and soil processing rates. This testing could be performed at the Joy Manufacturing Company test facility in Colorado Springs, Colorado, at a nominal cost and with no permitting requirements.
4. Continue economic evaluation to identify and estimate the appropriate procurement and contracting costs.

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2. INTRODUCTION

The objective of this report is to provide a detailed economic evaluation of alternative full-scale options for low temperature thermal stripping of VOC's from soil at U.S. Army installations. The following subsections provide an overview of the technology status, discussion of the pilot study, process descriptions of the alternatives evaluated, and a description of the general approach and assumptions for this economic evaluation.

2.1 Technology status. Soils at several U. S. Army Materiel Command (AMC) installations have been contaminated with a variety of organic compounds. In many cases, the contaminated soil has resulted in the degradation of underlying groundwater supplies.

To limit further contaminant migration, the U. S. Army Toxic and Hazardous Materials Agency (USATHAMA) is investigating technologies to effectively treat the contaminated soil. One treatment alternative is low temperature thermal stripping of volatile organic compounds (VOC's) from soil. A pilot study was conducted at Letterkenny Army Depot (LEAD) near Chambersburg, Pennsylvania from 5 August 1985 to 16 September 1985. The study was conducted to determine the feasibility of this technology for future remedial action projects at Department of Defense (DOD) installations.

Soils from two lagoons used for the disposal of organic liquids were chosen for treatment. This selection was based on the type, variety, concentration, and volatile nature of the compounds found in the area. Two types of soil existed at this site: fill soil and native soil. A grain-size analysis indicated that the fill material consisted of gravelly sands, while the native soil consisted of sandy clay/sandy silt.

Soils were treated in a thermal processor, an indirect heat exchanger used to heat and dry the contaminated soil. The net effect of heating the soil was to evaporate volatile contaminants. A carrier gas (i.e., air) was introduced to the unit to enhance contaminant removal. Contaminants in the off-gases were thermally destroyed in an afterburner.

2.2 <u>Overview of the pilot investigation</u>. The pilot investigation was completed in two phases. Phase I consisted of 18 test runs to evaluate the effect on VOC removal efficiency of varying operating conditions, (i.e., soil discharge temperature, soil residence time, and air inlet temperature). The 18 test runs were designed in a matrix format to investigate three levels of soil discharge temperature: 50°C, 100°C, and 150°C; three levels of soil residence time: 30 minutes, 45 minutes, and 60 minutes; and two levels of air inlet temperature: ambient and 90°C. Phase I test runs were conducted from 5 August 1985 through 26 August 1985.

Phase II of the pilot study consisted of 10 "optimization" test runs. The purpose of the optimization runs was fourfold:

1. To evaluate the effect on VOC removal efficiency of varying operating conditions beyond the limits set for Phase I of the investigation (i.e., maximum soil discharge temperature and maximum soil residence time).
2. To evaluate the VOC removal rate along the length of the unit.
3. To evaluate the VOC removal efficiency associated with three "duplicate" test runs to determine if the treatment was consistent and comparable.
4. To evaluate the VOC removal efficiency associated with reprocessing treated soils that still contained a VOC residual.

Phase II test runs were conducted from 27 August 1985 through 16 September 1985.

The data from the pilot investigation was statistically analyzed using multiple linear regression techniques. The objective was to develop simple linear equations that would identify those input or controlled variables that had a significant impact on the concentration of total VOC's in the processed soils (i.e., treatment effectiveness). The statistical analysis techniques were successful. Statistically significant simple linear equations were developed for design of a full-scale system operating at low, medium, or high soil discharge temperature. The results of the pilot investigation are presented in Report No. AMXTH-TE- CR-86074, "Task 11. Pilot Investigation of Low Temperature Thermal Stripping of Volatile Organic Compounds (VOC's) from Soil," dated June 1986.

2.3 <u>Process/description</u>. The pilot system tested at LEAD served as the design basis for the full-scale systems evaluated in this report. Prior to describing the full-scale systems evaluated, a process description of the pilot system is provided.

2.3.1 Pilot system tested at LEAD. Figure 1 provides an overall view of the low temperature thermal stripping pilot system installed at LEAD. Figure 2 provides a schematic illustration of the pilot system and describes the basic principles of operations. The thermal processor is a commercially available indirect heat exchanger which is commonly used to heat, cool, or dry bulk solids, slurries, pastes, or viscous liquids. For the pilot study, the thermal processor was used to heat and consequently dry the contaminated soil. The net effect of heating the soil was to evaporate the VOC's from the soil. Once volatilized, the VOCs were thermally destroyed in an afterburner. The following subsections provide a more detailed description of the pilot system.

2.3.1.1 Soil feed system. Depending upon the desired soil residence time, the soil feed rate varied throughout the pilot investigation from 100 to 265 pounds of soil per hour. However, the cycle feed rate (i.e., weight of soil per loading cycle) remained constant. Approximately 10 pounds of soil per loading cycle were fed to the unit at regular intervals. An air-tight rotary valve mechanism was used to introduce soil to the thermal processor.

2.3.1.2 Thermal processor. A photograph of the front view of the thermal processor is shown on Figure 3. The thermal processor consisted of a jacketed trough which housed a double-screw mechanism. The Holo-Flite® screws were seven inches in diameter and ran the entire length of the trough. The screw shafts and flights were hollow to accommodate circulation of the heat transfer liquid (i.e., hot oil). The oil flowed through the flights in a direction concurrent to the movement of the soil. The oil entered the unit at the soil feed end of the processor, circulated through the flights, and flowed back through the shaft to exit the unit at the same end that it entered. The trough jacket also circulated hot oil, providing additional heat exchange with the soils being processed.

The side clearance between the screws and the trough was 1/2 inch and the bottom clearance was 3/4 inch. The screws were driven at various rotational speeds via a chain drive connected to the gear reducer located beneath the conveyor. The continuous action of the screws promoted forward movement of the soil through the trough. The screws were set in the trough so that the flights of the two screws intermeshed to break up the soil and improve heat transfer.

FIGURE 1 INSTALLED PILOT SYSTEM

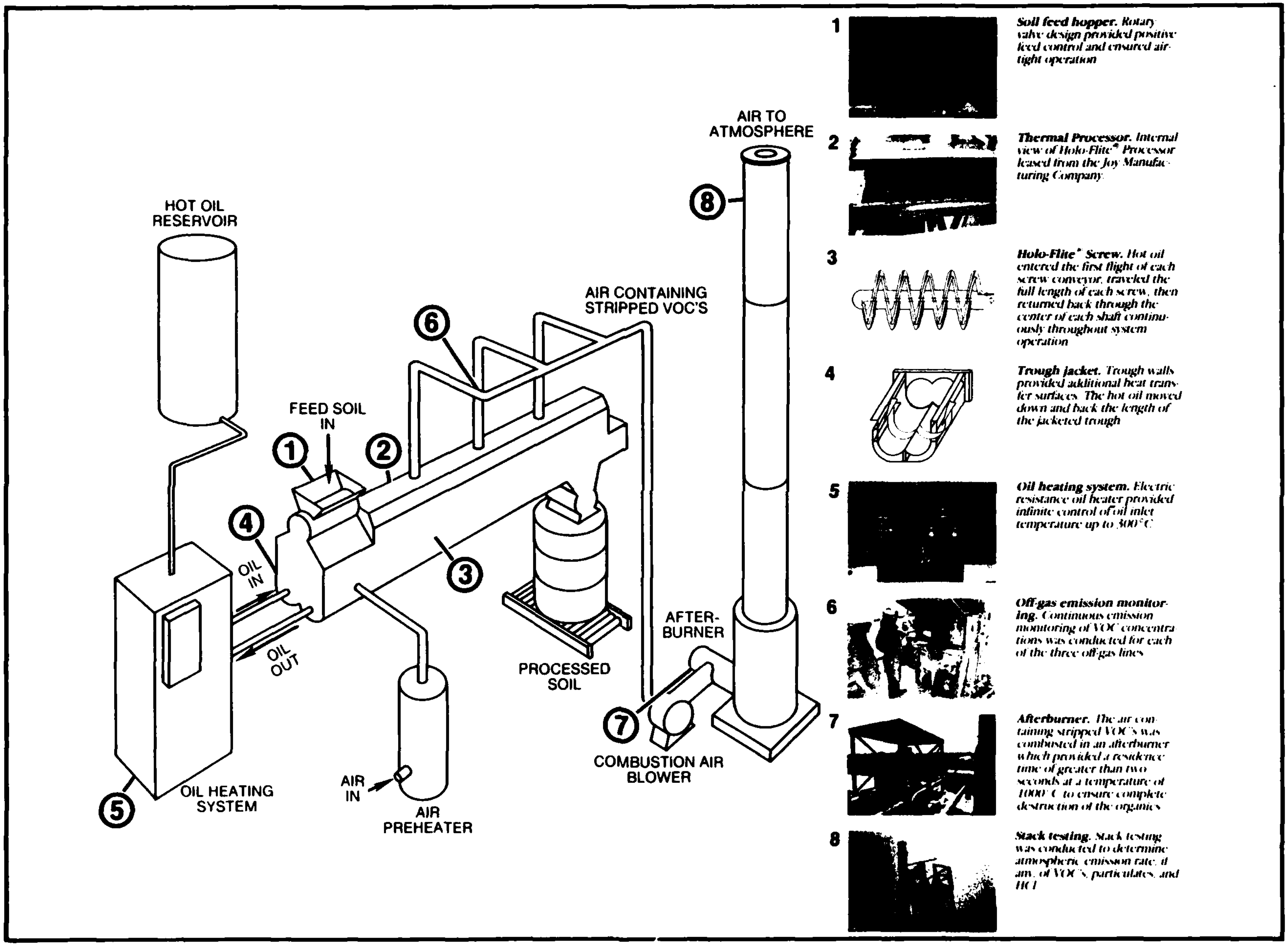

FIGURE 2 SCHEMATIC ILLUSTRATION OF THE LOW TEMPERATURE THERMAL STRIPPING PILOT SYSTEM

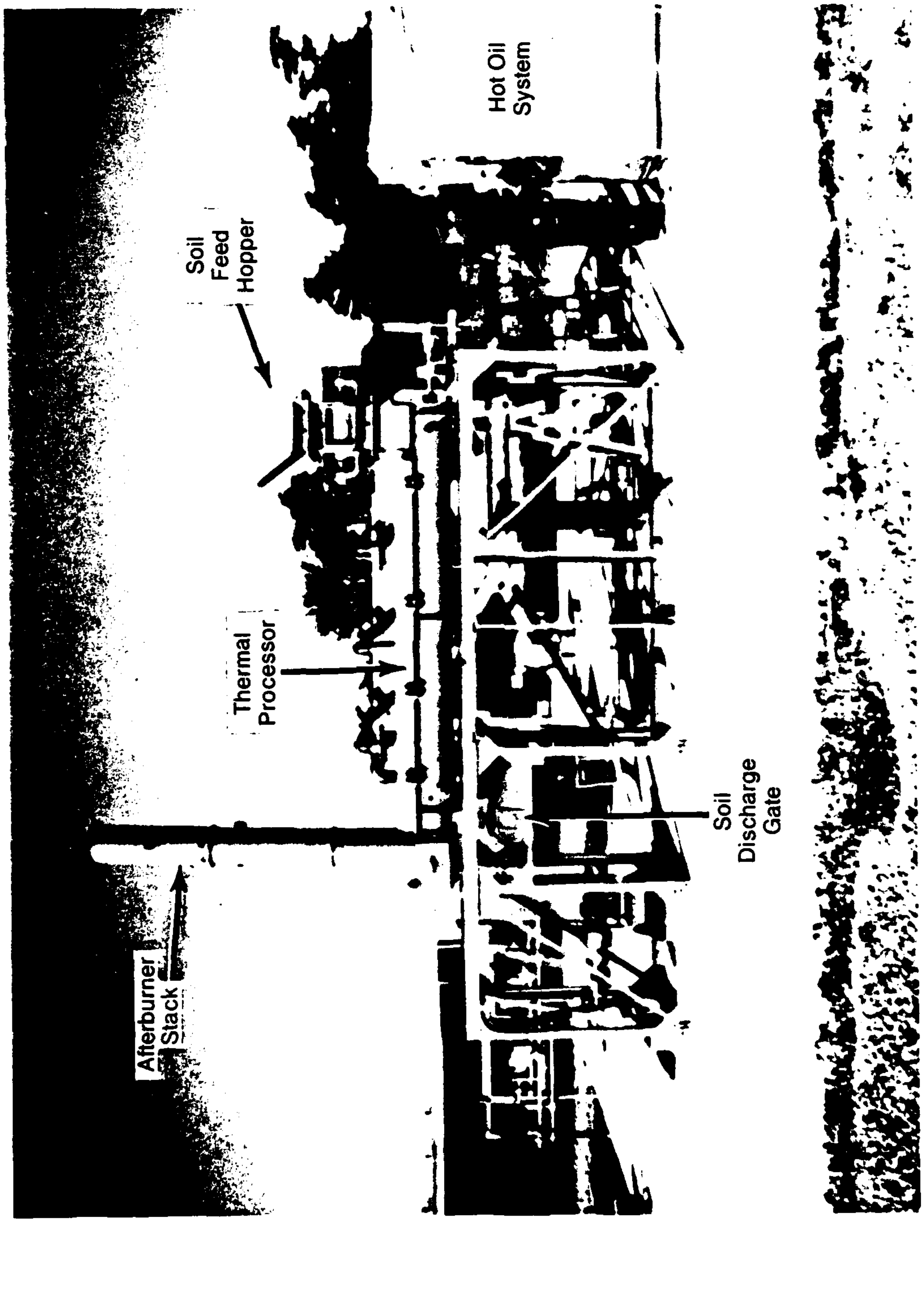

FIGURE 3 FRONT VIEW OF THE THERMAL PROCESSOR

The area above the twin screws was covered by a hood as shown in Figure 4. The hood was equipped with three vertical plates that extended from the top of the hood to within a small clearance of the twin screws. The plates separated the head space in the unit into three equally sized sections. One air exhaust port was connected to each section to facilitate removal of vapors via three exhaust lines.

2.3.1.3 Processed soil handling system. The discharge end of the Holo-Flite® processor incorporated an air-tight rotary valve mechanism, similar to that used in the feed system. The air lock sealed the unit from air infiltration and prevented excessive dust generation within the unit.

The continuous discharge of soil was collected in open top 55-gallon drums. A fabric shroud and sealing band around the top of the processed soil drum minimized fugitive dust emissions. The drums were situated on a roller conveyor to facilitate removal and replacement.

2.3.1.4 Hot oil system. The source of heating fluid for the thermal processor was a Chromalox Type COS Hot Oil Heat Transfer System: Model COSX-650-80, rated at 80 kilowatts at 480 volts. The heat exchange fluid was Monsanto Therminol 66, which had a temperature range of ambient to 315°C (600°F).

The system was self-contained and consisted of an oil reservoir, heater element system, temperature control system, expansion tank, high temperature pump, controls, and steel housing.

The hot oil for a given test was delivered via piping and valving to each of the Holo-Flite® screws and subsequently to the thermal processor trough.

2.3.1.5 Air systems. A purge gas (i.e., air) was circulated through the unit to enhance contaminant removal. The air passed through a preheater and entered the thermal processor at a controlled temperature. Once inside, the air stream was forced to travel a tortuous path by flowing through the divided sections of the processor. Off-gases were removed through three ports located in the hood of the processor, as shown in Figure 5. The 3-leg manifold combined into a main header. A fan was located downstream of the header and induced air flow through the system. A brief description of the individual components of the air system is contained in the following subsections.

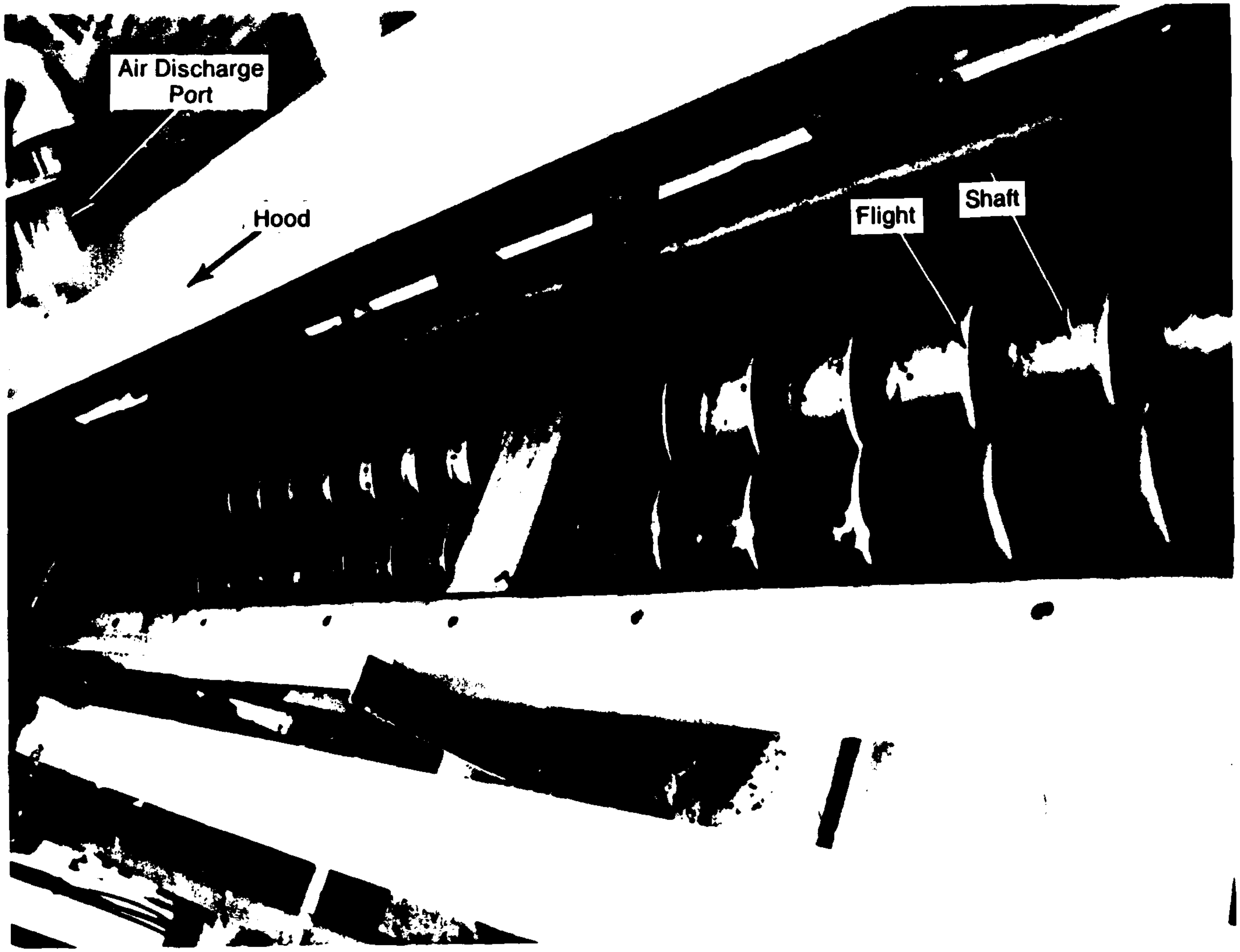

FIGURE 4 INTERNAL VIEW OF THERMAL PROCESSOR

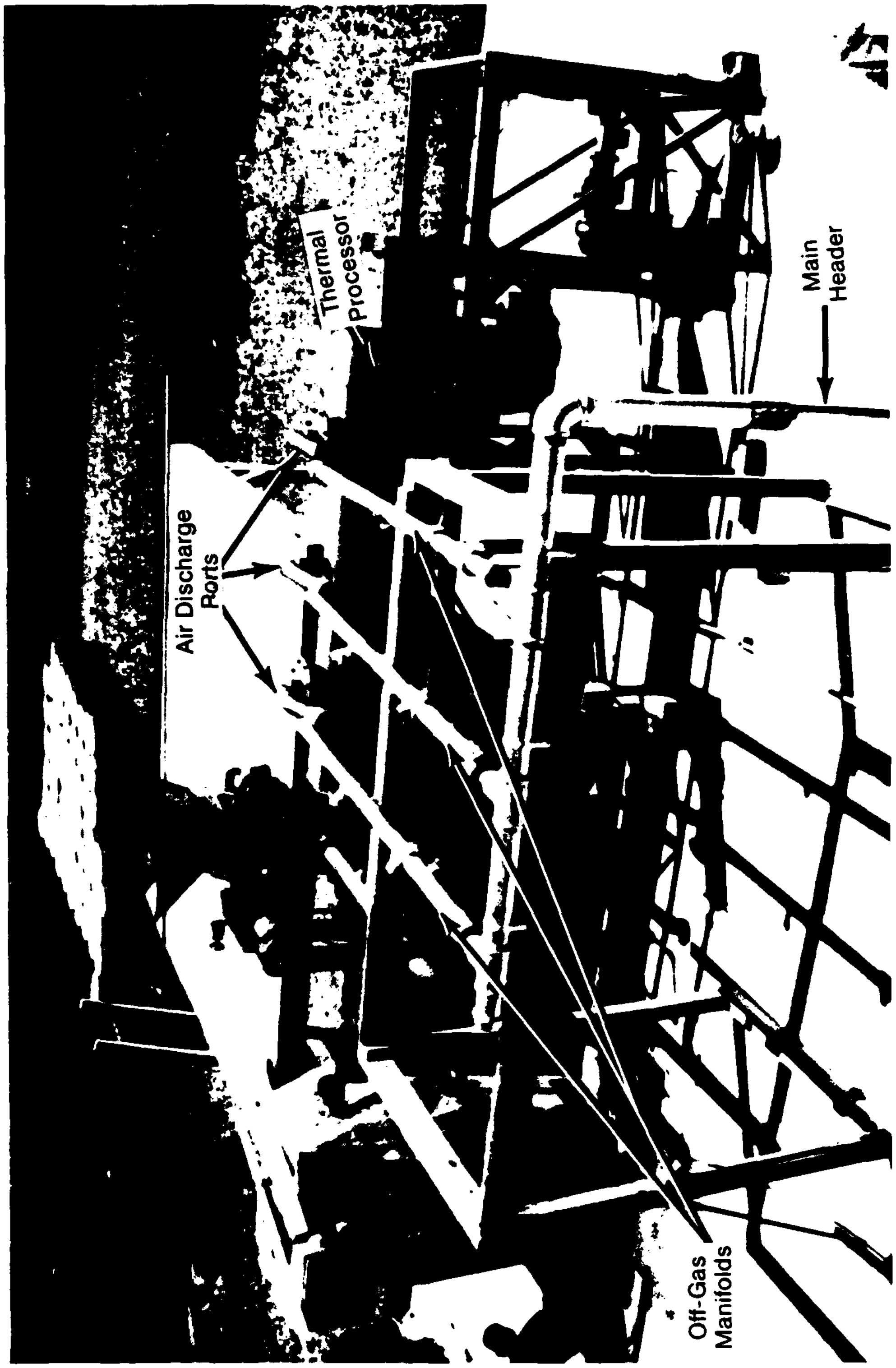

FIGURE 5 OFF-GAS DISCHARGE LINES

2.3.1.5.1 Air preheater. A Chromalox Process Heater (Model GCH-60905-E4) was used to heat the purge air during selected test runs. The electrical resistance heater was rated at 9 kilowatts at 480 volts. It was equipped with a temperature control system that enabled the temperature of the air to be heated from ambient to approximately 90°C (200°F).

2.3.1.5.2 Off-gas manifold system. The purge air and volatilized moisture and organics were removed through the three ports located in the hood. Each leg of the manifold system contained an air orifice for balancing air flows as well as individual ports for off-gas sampling. The manifolds fed into a main header which had its own test port. The main header was ducted to the entry of the induced draft fan. The main header contained a damper to regulate the flow of air through the thermal processor. In the fully open position, approximately 200 dry standard cubic feet per minute (dscfm) of air flowed through the system. The minimum air flow, corresponding to a nearly closed position, was approximately 75 dscfm.

2.3.1.5.3 Induced draft fan. An induced draft fan was located downstream of the manifold system. It provided the motive power to induce air flow through the system. The discharge of the fan was fed directly into the afterburner and served as combustion air.

2.3.1.6 Emission control system.

2.3.1.6.1 Afterburner. The afterburner operated at a minimum temperature of 1,000°C (1,800°F) and a residence time of greater than two seconds. The afterburner was propane-fired using a North American burner rated at 1.5×10^6 Btu/hr. Safety controls on the burner included a combustion air pressure switch, gas low pressure switch, gas high pressure switch, burner safety control system, low fire switch, and ultraviolet (UV) flame safety.

2.3.1.6.2 Refractory-lined stack. The refractory-lined stack was 18 inches in diameter and 20 feet high. It housed two thermocouples: the first for controlling burner temperature and the second for a system high temperature alarm.

2.3.1.6.3 Propane system. Two propane tanks were available to provide fuel for thermal destruction of the VOC's. The propane was piped directly from the tanks to the gas train of the afterburner system.

2.3.2 Full-scale systems evaluated. Figure 6 presents a schematic process diagram of the two full-scale systems evaluated during this economic analysis:

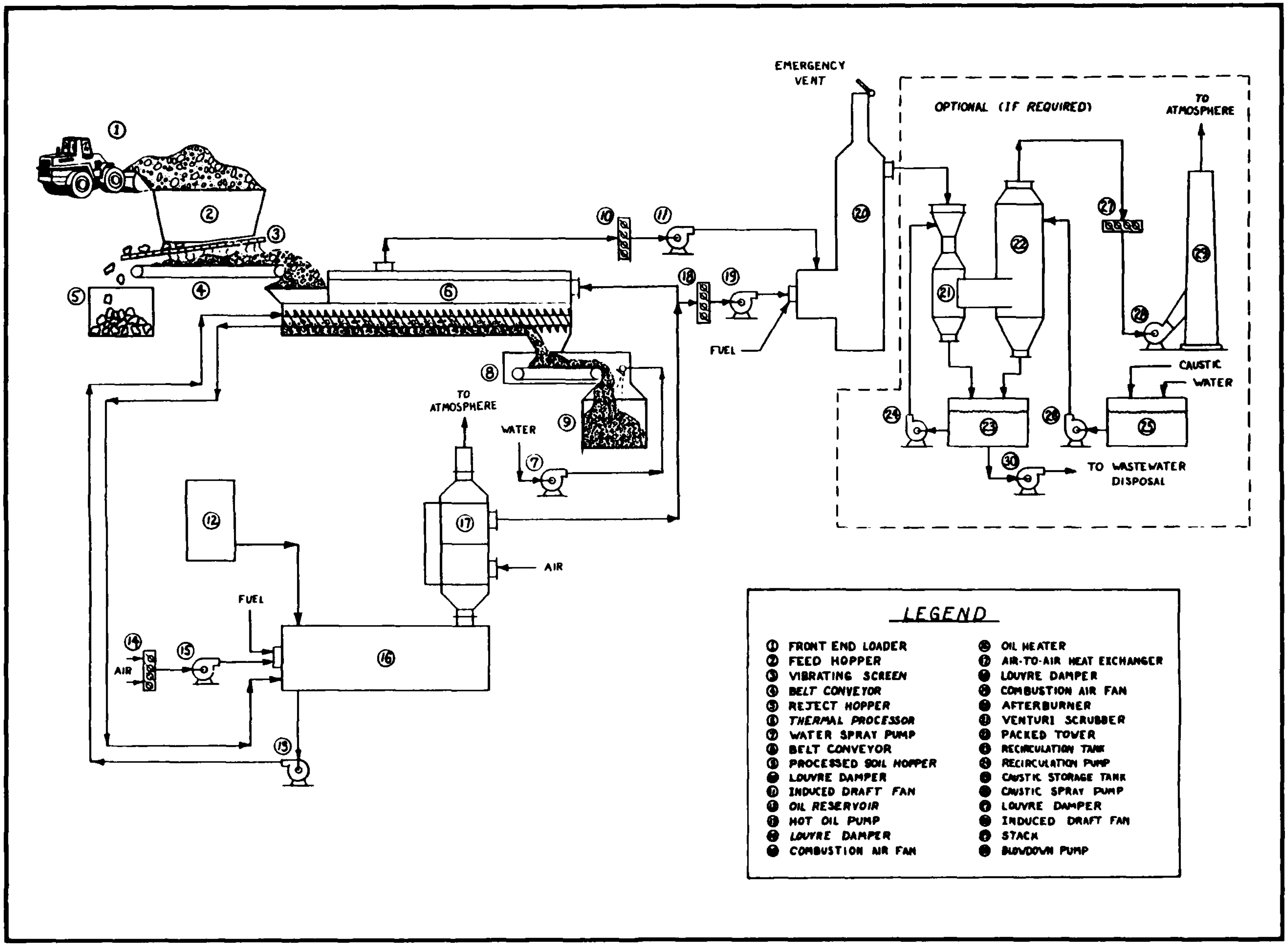

FIGURE 6 SCHEMATIC PROCESS DIAGRAM OF THE FULL-SCALE LOW TEMPERATURE THERMAL STRIPPING SYSTEM

(a) Option 1 - Without Flue Gas Scrubbing
(b) Option 2 - With Flue Gas Scrubbing

The dashed lines in Figure 6 indicate the additional equipment required for the flue gas scrubbing system in Option 2. The following subsections provide descriptions of these two alternative system configurations.

2.3.2.1 Option 1 - Without flue gas scrubbing. As shown in Figure 6, the Option 1 system configuration consists of the following major equipment items:

Equipment No.	Description
1	Front end loader - Reclaims feed soil from a stockpile located adjacent to the processing site and loads the soil into the feed hopper.
2	Feed hopper - Provides surge capacity for the soil feed system.
3	Vibrating screen - Provides both feed control and size classification of the feed soil. Oversized rocks and debris are sent to the reject hopper.
4	Belt conveyor - Provides feed control in combination with the vibrating screen and conveys soil to the thermal processor.
5	Reject hopper - Provides collection and storage of oversize rocks and debris.
6	Thermal processor - Heats the soil and volatilizes the VOCs for subsequent thermal destruction in the afterburner.
7	Water spray pump - Provides a water spray to cool and compact the processed soil and to minimize fugitive dust emissions.
8	Belt conveyor - Conveys the processed soil from the discharge of the thermal processor to the processed soil hopper.
9	Processed soil hopper - Provides collection and storage of the processed soil.

Equipment No.	Description
10	Louvre damper - Provides flow control of sweep air and maintains a slight negative pressure within the thermal processor.
11	Induced draft fan - Induces sweep air flow through the thermal processor and delivers the volatilized VOC's to the afterburner.
12	Oil reservoir - Provides storage and thermal expansion capacity for the hot oil system.
13	Hot oil pump - Provides flow control and circulation of the hot oil to and from the thermal processor.
14	Louvre damper - Provides flow control of combustion air to the oil heater.
15	Combustion air fan - Provides forced combustion air supply to the oil heater.
16	Oil heater - Provides the necessary indirect-fired heating of the oil which in turn provides indirect heating of the soil in the thermal processor.
17	Air-to-air heat exchanger - Provides heat recovery through preheat of the purge air and combustion air for the afterburner.
18	Louvre damper - Provides flow control of combustion air to the afterburner.
19	Combustion air fan - Provides forced combustion air supply to the afterburner.
20	Afterburner - Provides thermal destruction of the VOC's and converts volatilized chlorinated or halogenated compounds into HCl.

2.3.2.2 Option 2 - With flue gas scrubbing. As shown in Figure 6, the Option 2 system configuration includes all of the Option 1 equipment plus the following additional major equipment items:

Equipment No.	Description
21	Venturi scrubber -Provides quenching (e.g., desuperheating) of the flue gas and particulate emission control.
22	Packed tower - Provides acid gas (i.e., HCl) emission control.
23	Recirculation tank - Provides storage and surge capacity for the scrubber water recirculated to the scrubber system.
24	Recirculation pump - Provides flow control and fluid pressure for the scrubber recirculation system.
25	Caustic storage tank - Provides storage and surge capacity for the caustic scrubber water make-up system.
26	Caustic spray pump - Provides flow control and fluid pressure for the caustic scrubber water make-up system.
27	Louvre damper - Provides flow control of scrubbed combustion gases to the induced draft fan.
28	Induced draft fan - Induces flow of combustion gases through the scrubber system and delivers the scrubbed combustion gases to the stack.
29	Stack - Discharges the scrubbed combustion gases to the atmosphere.
30	Blowdown pump - Provides flow control and fluid pressure for transferring the scrubber blowdown to the wastewater disposal facilities.

2.4 General approach and economic assumptions. The objective of this report is to present an evaluation of the economics of low temperature thermal stripping of VOC's from soil for various size sites. In order to accomplish these objectives, this report follows the general approach outlined below:

(a) Four separate sizes of low temperature thermal stripping (LTTS) systems are evaluated in order to determine the sensitivity of project costs to alternative system sizes.
(b) Two separate system configurations are evaluated (i.e., Option 1 - Without Flue Gas Scrubbing, and Option 2 - With Flue Gas Scrubbing) in order to determine the sensitivity of project costs to the requirement for flue gas scrubbing.
(c) Three separate quantities of soil to be processed are evaluated in order to determine the sensitivity of project costs to site size (i.e., soil quantity) and to determine which system sizes are most cost effective for various size sites.
(d) A uniform set of economic assumptions are established for all options evaluated so that the costs can be compared on an "apples-to-apples" basis. A sensitivity analysis is presented in Section 6 to determine the impact upon project costs of varying the economic assumptions.

2.4.1 Alternative LTTS system sizes evaluated. In order to select the alternative LTTS system sizes to be evaluated, the following selection criteria were established:

(a) All LTTS systems must be transportable (i.e., size and weight of largest system component suitable for over-the-road truck shipment) preferably without requiring special permits for oversize or overweight transport.
(b) All LTTS system components had to be commercially available "off-the-shelf" items with proven operating experience in other applications.
(c) All thermal processors must be of the double-screw or quad-screw design, due to the improved materials handling and heat transfer capability of these designs compared to a single screw unit.
(d) All screws must be as large in diameter as practical (i.e., 24 inches) in order to minimize the sensitivity of the mechanical operation of the thermal processor to rocks, sticks, and debris, and to minimize the extent of prescreening of the feed soil required.

(e) All thermal processors must be designed to use hot oil as the indirect heat transfer agent instead of steam, since hot oil will allow considerably higher operating temperatures, if required.

(f) All thermal processors should be as long as practical (i.e., 24 feet) in order to allow higher rotational speeds to improve heat transfer characteristics and to provide longer residence times, if required.

(g) Multiple units (i.e, either in series or parallel) are acceptable. However, they should be identical units to ensure spare parts interchangeability.

(h) With regard to the method of procurement, it is assumed that a "turnkey" contractor would own and operate the LTTS system. If the government decides to purchase the system and operate the equipment under a separate contract, additional costs will be incurred which are not considered in this analysis (See Subsection 2.4.4 (h) and (i)).

Based upon the above criteria, four separate LTTS system sizes were selected, as summarized in Table 1. A brief description of each system is provided below:

(a) System A - The smallest capacity system evaluated, System A consists of a single unit of the double-screw design. The Holo-Flite® screws are 24 inches in diameter and 24 feet long. This is the largest screw diameter and longest screw shaft length commercially available. A detailed design drawing for the D-2424 Holo-Flite® processor and vapor hood cover is presented in Figure 7.

(b) System B - The next larger capacity system evaluated, System B consists of a single unit of the quad-screw design. The Holo-Flite® screws are identical in diameter and length to System A. However, the design incorporates four screws instead of two. Figure 8 provides general outline and installation dimensions for the Q-2424 Holo-Flite® processor.

(c) System C - System C consists of two of the quad-screw thermal processors described under System B arranged in series (i.e., the processed soil discharges from the first unit into the feed hopper of the second unit). This configuration is preferred to two separate parallel units since it provides a faster screw rotational speed which results in better material agitation and improved heat transfer efficiency.

TABLE 1. SUMMARY OF FOUR SEPARATE LOW TEMPERATURE THERMAL STRIPPING SYSTEMS EVALUATED

Description	System A	System B	System C	System D
THERMAL PROCESSOR DATA				
Model Number	D-2424-6	Q-2424-6	Q-2424-6	Q-2424-6
Number of Units	1	1	2	4
Design Type	Double-Screw	Quad-Screw	Quad-Screw	Quad-Screw
Diameter of Screws, Inches	24	24	24	24
Length of Screws, Feet	24	24	24	24
Spacing Between Screw Flights, Inches	6	6	6	6
Configuration	Single Unit	Single Unit	Two units in series	Two parallel trains, each with two units in series
PROCESSING DATA @ 20% MOISTURE CONTENT SOIL:				
Soil Feed Rate, lbs/hr	7,500	15,250	30,500	61,000
Screw Speed, RPM	1.3	1.4	2.8	2.8
Soil Residence Time, Minutes	54.0	46.9	23.5 (each)	23.5 (each)
Soil Discharge Temperature, °F	400	400	400	400
Oil Inlet Temperature, °F	600	600	600	600
Oil Outlet Temperature, °F	530	530	530	530
Oil Flowrate, GPM	204	416	831	1,663
PROCESSING DATA @ 30% MOISTURE CONTENT SOIL:				
Soil Feed Rate, lbs/hr	5,500	11,000	22,200	44,400
Screw Speed, RPM	1.0	1.0	2.0	2.0
Soil Residence Time, Minutes	73.0	65.0	32.2 (each)	32.2 (each)
Soil Discharge Temperature, °F	400	400	400	400
Oil Inlet Temperature, °F	600	600	600	600
Oil Outlet Temperature, °F	530	530	530	530
Oil Flowrate, GPM	209	414	835	1,670

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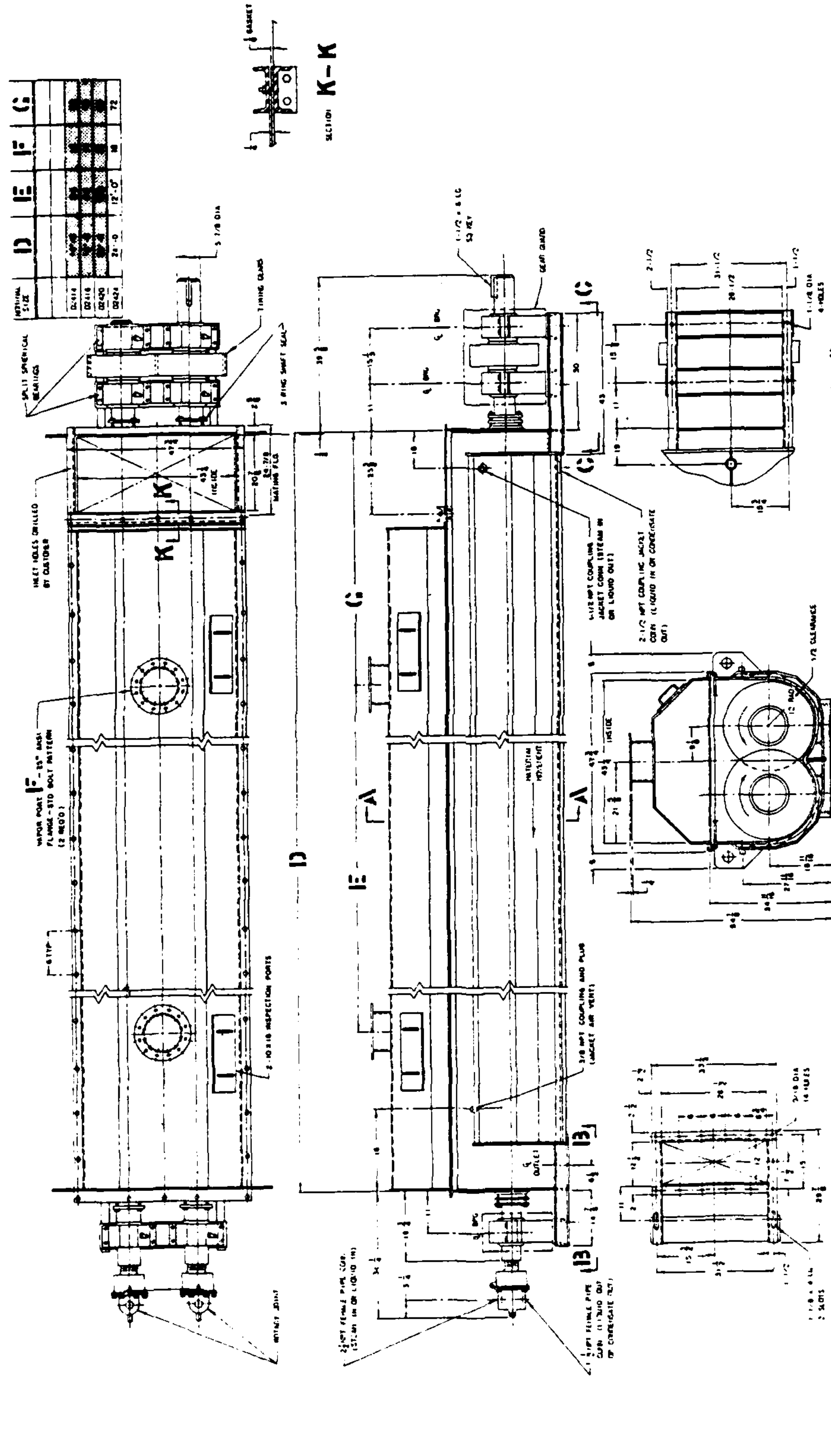

FIGURE 7 DOUBLE-SCREW HOLO-FLITE® PROCESSOR AND VAPOR HOOD (SYSTEM A)

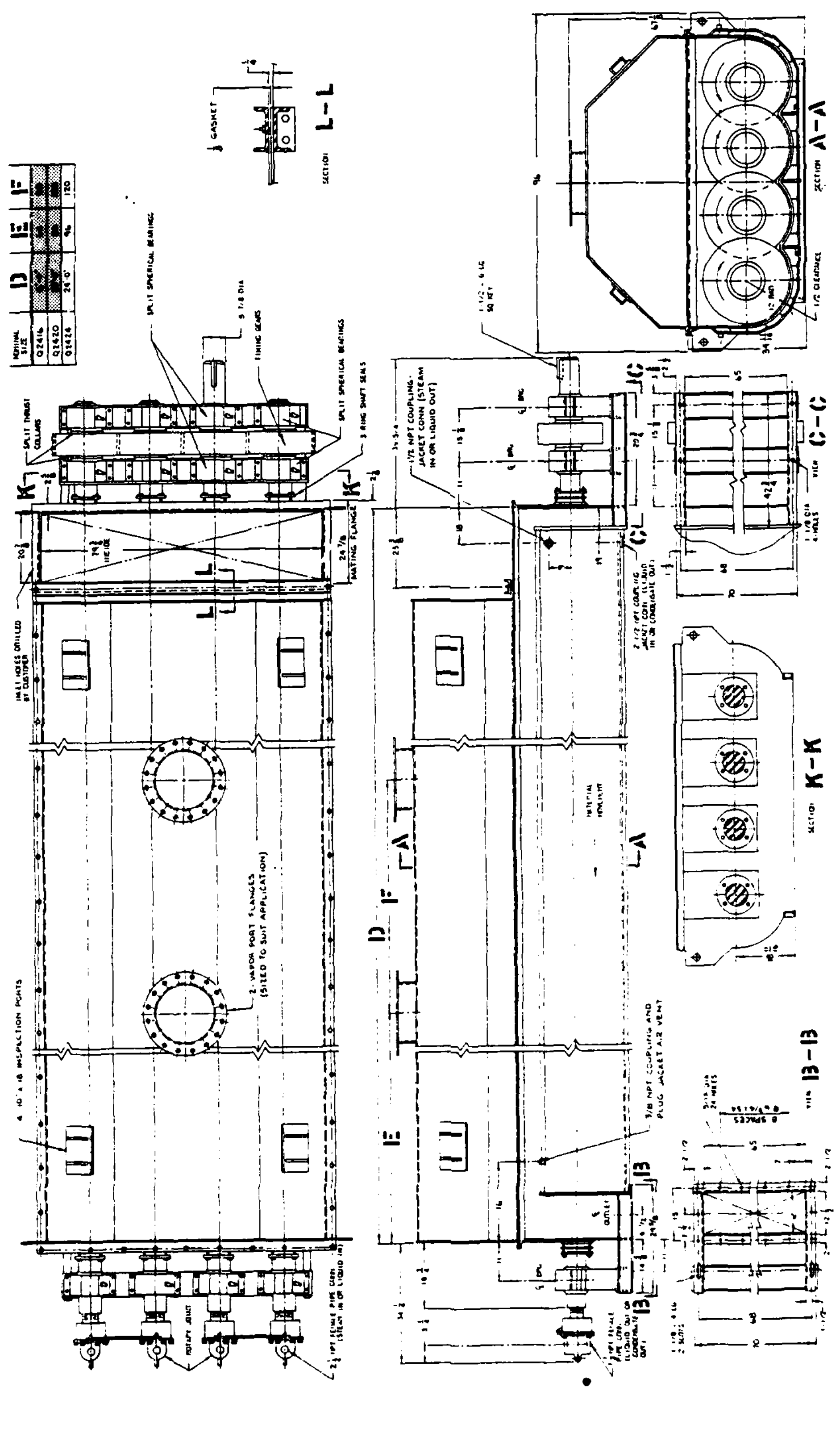

FIGURE 8 QUAD-SCREW HOLO-FLITE® PROCESSOR AND VAPOR HOOD (SYSTEMS B AND C)

(d) System D - The largest capacity system evaluated, System D consists of four of the quad-screw thermal processors described under System B. System D consists of two of the System C configurations installed in parallel. This configuration is preferred to four units in series since operational difficulties in one unit would only result in downtime in one of the two parallel trains, thereby improving system availability.

2.4.2 Alternative system configurations evaluated. Two separate system configurations are evaluated for each system size as described previously in Subsection 2.2.2 and shown previously in Figure 6. These system configurations are as follows:

(a) Option 1 - Without Flue Gas Scrubbing (Reference Subsection 2.2.2.1)
(b) Option 2 - With Flue Gas Scrubbing (Reference Subsection 2.2.2.2)

Summaries of the LTTS system data for Options 1 and 2 are presented in Tables 2 and 3, respectively.

2.4.3 Alternative quantities of soil to be processed. Three separate size sites (i.e., quantities of soil to be processed) are evaluated. These site sizes are as follows:

(a) Site 1 - 1,000 tons (741 cubic yards)[1]
(b) Site 2 - 10,000 tons (7,407 cubic yards)[1]
(c) Site 3 - 100,000 tons (74,074 cubic yards)[1]

In order to ensure a common basis for comparison of each alternative at each site, it is assumed that the characteristics of the contaminated soil at each site are identical as summarized below:

(a) Soil type: Silty clay with sand, gravel, and metallic and non-metallic debris.
(b) Soil density prior to excavation: Average - 100 lbs/ft^3; Range - 90-110 lbs/ft^3
(c) Soil bulk density after excavation: Average - 75 lbs/ft^3; Range - 65-85 lbs/ft^3

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[1]Assumes an average soil density of 100 lbs/ft^3 prior to excavation.

TABLE 2. SUMMARY OF LTTS SYSTEM DATA FOR OPTION 1 - WITHOUT FLUE GAS SCRUBBING

Description	System A	System B	System C	System D
THERMAL PROCESSOR DATA				
Model Number	D-2424-6	Q-2424-6	Q-2424-6	Q-2424-6
Number of Units	1	1	2	4
Soil Feed Rate, lbs/hr	7,500	15,250	30,500	61,000
Soil Moisture Content, %	20	20	20	20
Soil Discharge Temperature, °F	400	400	400	400
Soil Residence Time, minutes	54	47	47	47
Fuel Requirements, 10^6 Btu/hr	2.75	5.6	11.21	22.4
Sweep Air Flowrate, ACFM	500	500	1,000	2,000
Sweep Air Temperature, °F	400	400	400	400
Total Air Flow to Afterburner, ACFM	1,165	1,864	3,728	7,456
Air Temperature to Afterburner, °F	272	247	247	247
Relative Humidity, %	4.9	24.3	24.3	24.3
AFTERBURNER DATA				
Number of Units	1	1	1	2
Inside Diameter, Feet	5.0	6.0	7.0	7.0
Inside Length, Feet (Each)	12.0	13.5	20.0	20.0
Refractory Thickness, Inches	9	9	9	9
Burner Size, 10^6 Btu/hr (Each)	5.0	7.5	15.0	15.0
Fuel Requirements, 10^6 Btu/hr (Each)	3.9	6.4	12.5	12.5
Exit Gas Temperature, °F	1,800	1,800	1,800	1,800
Exit Gas Flowrate, ACFM	6,978	11,523	22,786	45,572
Gas Retention Time, Seconds	2.0	2.0	2.0	2.0
SCRUBBER DATA				
Number of Units	N/A	N/A	N/A	N/A
Exit Gas Temperature, °F	N/A	N/A	N/A	N/A
Exit Gas Flowrate, ACFM	N/A	N/A	N/A	N/A
UTILITIES				
Fuel Type	Propane	Propane	Propane	Propane
Fuel Burn Rate, 10^6 Btu/hr	6.65	12.0	23.7	47.4
Electrical Requirements, kW				
Water Consumption, gallons/hr	105	210	420	840
Scrubber Blowdown, gallons/hr	N/A	N/A	N/A	N/A

TABLE 3. SUMMARY OF LTTS SYSTEM DATA FOR OPTION 2 - WITH FLUE GAS SCRUBBING

Description	System A	System B	System C	System D
THERMAL PROCESSOR DATA				
Model Number	D-2424-6	Q-2424-6	Q-2424-6	Q-2424-6
Number of Units	1	1	2	4
Soil Feed Rate, lbs/hr	7,500	15,250	30,500	61,000
Soil Moisture Content, %	20	20	20	20
Soil Discharge Temperature, °F	400	400	400	400
Soil Residence Time, Minutes	54	47	47	47
Fuel Requirements, 10^6 Btu/hr	2.75	5.6	11.2	22.4
Sweep Air Flowrate, ACFM	500	500	1,000	2,000
Sweep Air Temperature, °F	400	400	400	400
Total Air Flow to Afterburner, ACFM	1,165	1,864	3,728	7,456
Air Temperature to Afterburner, °F	272	247	247	247
Relative Humidity, %	4.9	24.3	24.3	24.3
AFTERBURNER DATA				
Number of Units	1	1	1	2
Inside Diameter, Feet	5.0	6.0	7.0	7.0
Inside Length, Feet (Each)	12.0	13.5	20.0	20.0
Refractory Thickness, Inches	9	9	9	9
Burner Size, 10^6 Btu/hr (Each)	5.0	7.5	15.0	15.0
Fuel Requirements, 10^6 Btu/hr (Each)	3.9	6.4	12.5	12.5
Exit Gas Temperature, °F	1,800	1,800	1,800	1,800
Exit Gas Flowrate, ACFM	6,978	11,523	22,786	45,572
Gas Retention Time, Seconds	2.0	2.0	2.0	2.0
SCRUBBER DATA				
Number of Units	1	1	1	2
Exit Gas Temperature, °F	195	195	195	195
Exit Gas Flowrate, ACFM	3,780	6,160	12,300	24,600
UTILITIES				
Fuel Type	Propane	Propane	Propane	Propane
Fuel Burn Rate, 10^6 Btu/hr	6.65	12.0	23.7	47.4
Electrical Requirements, kW				
Water Consumption, gallons/hr	805	1,380	2,760	5,520
Scrubber Blowdown, gallons/hr	300	500	1,000	2,000

(d) Soil moisture content: Average - 20%
Range - 15-30%

(e) Soil contamination: Various volatile organic compounds (VOCs) in concentrations up to 20,000 ppm.[1]

(f) Soil Clean-up objectives: Less than 5 ppm of any individual VOC in the processed soil.

2.4.4 General economic assumptions. The following general economic assumptions are applicable to each alternative evaluated at each site:

(a) It is assumed that excavation and process operations can be conducted during all 12 months of the year. However, some site excavation operations may not be practical during severe winter months. This analysis assumes that either year-round excavation is practical, or that sufficient quantities of contaminated soils can be excavated and stockpiled to support process operations during severe winter months.

(b) It is assumed that excavation operations are conservatively limited to 6 hours per day to ensure daylight operations with adequate time allowance for equipment and personnel decontamination.

(c) The excavation system, transportation system, materials handling and feed system, and thermal processor system are designed to handle saturated soils. However, treatment of groundwater or standing lagoon water is beyond the scope of this analysis.

(d) It is assumed that the soil does not contain heavy metals that will cause an EP toxicity problem, and that the processed soil will be suitable for on-site disposal as backfill once the clean-up objectives have been demonstrated.

(e) All capital costs, as well as operation and maintenance costs, are valued in January 1986 dollars.

(f) This analysis assumes zero inflation to escalate either project capital costs or operation and maintenance (O&M) costs. Thus, the analysis results are in "real" terms (1986 dollars). This avoids the complications associated with assuming future inflation conditions.

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[1]Results of pilot testing conducted at the Letterkenny Army Depot (Reference: Report No. AMXTH-TE-CR-86074, June 1986) demonstrated that the LTTS system can effectively decontaminate soils containing organics with boiling points as high as 175°C.

(g) This economic analysis does address the estimated costs of environmental permitting. However, it does not attempt to address the cost associated with potential project delays due to regulatory review or approvals.

(h) The costs presented in this analysis are typical of the costs that would be obtained from a "turnkey" contractor responsible for the design, fabrication, construction, startup, performance testing, and operation of the system (including excavation and transportation of the soil to the site and disposal of process residuals). It is not assumed that the LTTS system is "leased" or "purchased" by the government. Rather, it is assumed that the government would contract for a service to be performed on a firm, fixed-unit-price basis (i.e., $/ton). It is conservatively assumed that the "turnkey" contractor would totally capitalize the equipment over the life of the project and that no salvage value for the equipment would be credited to the project.

(i) If the government decides to purchase the equipment and operate the equipment under separate contract, many costs will be incurred which are not considered in this analysis. These costs include, but are not limited to, the following:

- Government contracting costs.
- Requirements for rigorous Reliability and Maintainability (RAM) analyses.
- Requirements for extensive documentation, such as:
  - Technical drawing packages.
  - Detailed start-up, operating, shut-down, emergency, and maintenance procedures.
  - Detailed parts listing and inventory.
  - Detailed procedures for assembly, disassembly, and packaging for shipment.
  - Detailed equipment, instrumentation, and control systems operation and maintenance.
- Requirements for preparation, submission and approval of a detailed site plan and safety submission.
- Interest charges due to delayed payment schedules and retainages.
- Rigorous requirements for system and subsystem performance testing.

The costs presented in this analysis should not be used directly to estimate the government's total costs for appropriation purposes.

The above costs have not been included in this analysis, since they would only serve to confuse the comparison of this technology to other technologies. It is recommended that an additional pre-bid cost estimate be performed once the performance specifications, method of procurement, purchasing and documentation requirements, regulatory requirements, etc. are known to ensure that the estimate for appropriation will be adequate or will not be exceeded.

3. CAPITAL COSTS

The objective of this section of the analysis is to present the total direct and indirect capital costs for each of the alternative low temperature thermal stripping (LTTS) systems evaluated. Table 4 provides a summary of the capital costs for the Option 1 LTTS systems without flue gas scrubbing. Table 5 provides a similar summary of the capital costs for the Option 2 LTTS systems with flue gas scrubbing.

3.1 Direct capital costs. The direct capital costs presented in Tables 4 and 5 are based upon direct vendor quotations from the Denver Equipment Division of the Joy Manufacturing Company, located in Colorado Springs, Colorado. The contact at Joy is Mr. Daryl P. Jones, Engineering Manager, 303-471-3443. This is the same firm that manufactured the Holo-Flite® processor used during the field demonstration project conducted at the Letterkenny Army Depot.

3.2 Indirect capital costs. The indirect capital costs are based upon the data and assumptions presented in the following subsections.

3.2.1 Site preparation/mobilization. The site preparation/ mobilization activities include the following:

(a) Project mobilization:

- Assembling of equipment, materials, and supplies for shipment to the site.
- Progressive shipment of above items to the site as needed.

(b) Site preparation:

- Site grading and security fences. It is assumed that minimal site grading is required. A chain link security fence will be placed around the LTTS system. Active excavation areas will be enclosed with moveable snow fencing to preclude accidental intrusion into open holes.
- Construction and/or improvement of site access roads.
- Installation of foundations and pads and soil staging/storage areas.

TABLE 4. SUMMARY OF CAPITAL COSTS FOR OPTION 1 - WITHOUT FLUE GAS SCRUBBING

Capital Costs	System A	System B	System C	System D
DIRECT CAPITAL COSTS				
Holo-Flite® Processor(s)	152,000	250,000	500,000	1,000,000
Hot Oil System	42,600	58,000	84,600	169,200
Feed System	56,600	91,900	149,300	298,600
Processed Soil System	6,800	11,100	18,000	36,000
Afterburner	66,000	100,000	151,600	303,200
Flue Gas Scrubbing System	N/A	N/A	N/A	N/A
Piping and Electrical	48,600	76,700	135,500	271,100
Instrumentation & Controls	32,400	51,100	90,400	180,700
Total Direct Capital Costs	405,000	638,800	1,129,400	2,258,800
INDIRECT CAPITAL COSTS				
Site Preparation/Mobilization	98,800	120,000	154,400	210,100
Construction/Erection/Installation	101,000	156,900	267,300	534,500
Engineering	48,600	76,700	135,500	271,100
Permits	150,000	150,000	150,000	150,000
Start-Up and Training	101,300	107,300	149,400	195,400
Spare Parts	20,300	31,900	56,500	112,900
Freight	9,000	15,000	24,000	36,000
Site Closure/Demobilization	50,500	78,400	133,600	267,200
Contingency	147,700	206,200	330,000	605,400
Total Indirect Capital Costs	727,200	942,400	1,400,700	2,382,600
TOTAL CAPITAL COSTS	1,132,200	1,581,200	2,530,100	4,641,400

TABLE 5. SUMMARY OF CAPITAL COSTS FOR OPTION 2 - WITH FLUE GAS SCRUBBING

Capital Costs	System A	System B	System C	System D
DIRECT CAPITAL COSTS				
Holo-Flite® Processor(s)	152,000	250,000	500,000	1,000,000
Hot Oil System	42,600	58,000	84,600	169,200
Feed System	56,600	91,900	149,300	298,600
Processed Soil System	6,800	11,100	18,000	36,000
Afterburner	66,000	100,000	151,600	303,200
Flue Gas Scrubbing System	53,700	69,200	118,400	145,900
Piping and Electrical	56,700	87,000	153,300	292,900
Instrumentation & Controls	37,800	58,000	102,200	195,300
Total Direct Capital Costs	472,200	725,200	1,277,400	2,441,100
INDIRECT CAPITAL COSTS				
Site Preparation/Mobilization	105,000	130,000	170,600	236,500
Construction/Erection/Installation	123,800	186,300	317,600	596,500
Engineering	56,700	87,000	153,300	292,900
Permits	150,000	150,000	150,000	150,000
Start-Up and Training	125,800	136,400	188,900	255,700
Spare Parts	23,600	36,300	63,900	122,100
Freight	12,000	21,000	33,000	48,000
Site Closure/Demobilization	61,900	93,200	158,800	298,200
Contingency	169,600	234,800	377,000	666,200
Total Indirect Capital Costs	828,400	1,075,000	1,613,100	2,666,100
TOTAL CAPITAL COSTS	1,300,600	1,800,200	2,890,500	5,107,200

(c) Utilities installation:

- Electricity.
- Potable water supply.
- Telephone service.
- Fuel supplies.
- High temperature/high pressure water for decontamination of equipment.

(d) Installation of support facilities:

- Project command trailer.
- Decontamination trailer.
- Laboratory trailer.
- Equipment storage trailer.

(e) Installation of wastewater storage tanks:

- Decontamination rinse waters.
- Scrubber "blow down" water (Option 2 only).

(f) Implement site security.

3.2.2 Construction/erection/installation. The construction/erection/installation costs are estimated as a percentage of the direct capital costs. However, the percentages for shop assembled skid mounted components are considerably lower than for field assembled and erected components. The percentages assumed for each of the direct capital cost line items are as follows:

Direct capital cost item	Percentage Used to Estimate Construction/ Erection/ Installation Costs
(1) Holo-Flite® processor	10%
(2) Hot oil system	30%
(3) Feed system	20%
(4) Processed soil system	20%
(5) Afterburner	30%
(6) Flue gas scrubbing system (Option 2 only)	30%
(7) Piping and electrical	50%
(8) Instrumentation and controls	50%

3.2.3 Engineering. Project engineering costs are estimated as 7 percent of the total direct capital costs (TDCC). Project engineering does not include design engineering conducted by the equipment supplier (which is included in equipment costs), but does include off-site project engineering and project management

3.2.4 Permits. Permitting costs are very difficult to estimate at this time due to pending regulatory revisions which may substantially streamline the permitting process for on-site transportable thermal treatment units. However, based upon WESTON's current experience, typical permitting costs are $25,000 to $75,000 (an average of $50,000 is assumed for this analysis) for engineering support and regulatory agency liaison plus $50,000 to $150,000 (an average of $100,000 is assumed for this analysis) for trial burn testing, analysis, and reports. This does not include the operational costs for running the LTTS system during the trial burn testing period. These operational costs are covered under Subsection 3.2.5 - Start up and training.

3.2.5 Start-up and training. Start-up and training costs are based upon 2 weeks of labor costs as discussed in Subsection 5.2 plus 2 weeks of operation at design capacity (i.e., total operating costs for 2 weeks including labor). The 2 weeks of operation include the LTTS system operational costs during trial burn and performance testing. No credit is taken in this analysis for contaminated soil processed during the start-up and training period. It is assumed that full-scale operations will commence immediately after start-up and training is complete, and that no additional costs are incurred due to demobilizing and remobilizing the operating staff (this situation might occur if regulatory agencies would not grant operating permits until trial burn testing results are submitted and approved).

3.2.6 Spare parts. Spare parts are estimated based upon 5 percent of TDCC.

3.2.7 Freight. The freight costs are based upon the number of trucks required to ship the equipment to the site, assuming a distance from the point of manufacture to the site of 1,000 miles and a trucking cost of $3 per load mile. The estimated number of trucks required to ship the alternative systems evaluated are as follows:

Alternative system	Number of trucks required to transport the LTTS system to the site	
	Option 1 - without scrubber	Option 2 - with scrubber
System A	3	4
System B	5	7
System C	8	11
System D	12	16

3.2.8 Site closure/demobilization. The site closure/demobilization activities include the following:

(a) Equipment demobilization:

- Dismantling and off-site disposal of all structures that covered the LTTS system and soil staging/storage areas.
- Dismantling and removal of the LTTS system.
- Removal and off-site disposal of all concrete pads.
- Removal of the fuel storage tank(s) and the support facilities.
- Decontamination and removal of all project equipment.
- Final grading of earthen berms and stormwater flow diversion ditches around equipment and soil staging/storage areas to achieve a flat, gentle, sloping surface.

(b) Site restoration:

- Backfilling and grading of the excavation and processing areas to promote positive drainage of stormwater away from the excavation area.
- Installation of stormwater diversion ditches and erosion control devices.
- Seeding and mulching to provide vegetative cover.

3.2.9 Contingency. The contingency is estimated based upon 15 percent of the TDCC and other indirect capital costs.

4. OPERATING COSTS

The objective of this section of the analysis is to present the estimated operating costs for each of the alternative sizes and configurations of LTTS systems evaluated at each of the sites. Tables 6 through 11 provide a summary of this data as follows:

Table No.	Operating cost data summarized
6	Option 1 - Without flue gas scrubbing at Site 1 (1,000 ton site)
7	Option 1 - Without flue gas scrubbing at Site 2 (10,000 ton site)
8	Option 1 - Without flue gas scrubbing at Site 3 (100,000 ton site)
9	Option 2 - With flue gas scrubbing at Site 1 (1,000 ton site)
10	Option 2 - With flue gas scrubbing at Site 2 (10,000 ton site)
11	Option 3 - With flue gas scrubbing at Site 3 (100,000 ton site)

4.1 Equipment. Tables 12 and 13 provide a summary of the equipment costs on a weekly basis for Option 1 and Option 2, respectively. A brief description of each equipment item is presented in the following subsections.

4.1.1 Front end loaders. Two front end loaders are required for each system evaluated. One front end loader is required for excavation operations. A second front end loader is needed for reclaiming stockpiled soil from the contaminated soil storage area and feeding the soil to the LTTS system feed hopper. The excavation front end loader's bucket capacity was sized to allow excavation of one week's production supply of contaminated soil in only 30 hours of operation. The feed system front end loader's bucket size was selected to ensure less than six bucket loads per hour would be required to meet the design processing rate. As it turns out, in all cases the same size front end loader satisfies both requirements and provides some additional benefit in terms of redundancy and spare parts interchangeability.

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TABLE 6. OPERATING COSTS FOR OPTION 1 - WITHOUT FLUE GAS SCRUBBING AT SITE 1 (1,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$21,079	$12,750	$ 9,886	$ 7,386
LABOR	$23,415	$12,608	$10,007	$ 5,925
UTILITIES				
Fuel	$17,643	$17,140	$19,337	$19,340
Electricity	$ 795	$ 642	$ 612	$ 612
Water	$ 28	$ 30	$ 34	$ 34
Wastewater Disposal	$ 43	$ 30	$ 26	$ 17
Caustic	N/A	N/A	N/A	N/A
Oversize Debris Disposal	$ 401	$ 432	$ 498	$ 498
LABORATORY COSTS	$11,143	$ 6,000	$ 4,571	$ 2,286
MISCELLANEOUS SUPPLIES	$ 2,786	$ 1,500	$ 857	$ 429
CONTINGENCY at 15%	$11,600	$ 7,670	$ 6,874	$ 5,479
TOTAL OPERATING COSTS	$88,933	$58,802	$52,702	$42,006
TOTAL QUANTITY OF SOIL PROCESSED, TONS	1,000	1,000	1,000	1,000
OPERATING COSTS (UNIT COST BASIS)	$88.90/ton	$58.80/ton	$52.70/ton	$42.00/ton
TOTAL TIME REQUIRED	13 days	7 days	4 days	2 days

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TABLE 7. OPERATING COSTS FOR OPTION 1 - WITHOUT FLUE GAS SCRUBBING AT SITE 2
(10,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$212,245	$117,300	$ 79,580	$ 59,455
LABOR	$235,770	$115,994	$ 80,555	$ 47,693
UTILITIES				
Fuel	$177,650	$157,688	$155,664	$155,687
Electricity	$ 8,004	$ 5,906	$ 4,927	$ 4,927
Water	$ 281	$ 276	$ 276	$ 276
Wastewater Disposal	$ 430	$ 276	$ 207	$ 138
Caustic	N/A	N/A	N/A	N/A
Oversize Debris Disposal	$ 4,039	$ 3,974	$ 4,011	$ 4,011
LABORATORY COSTS	$112,200	$ 55,200	$ 36,800	$ 18,400
MISCELLANEOUS SUPPLIES	$ 28,050	$ 13,800	$ 6,900	$ 3,450
CONTINGENCY at 15%	$116,800	$ 70,562	$ 55,338	$ 44,106
TOTAL OPERATING COSTS	$895,469	$540,976	$424,258	$338,143
TOTAL QUANTITY OF SOIL PROCESSED, TONS	10,000	10,000	10,000	10,000
OPERATING COSTS (UNIT COST BASIS)	$89.50/ton	$54.10/ton	$42.40/ton	$33.80/ton
TOTAL TIME REQUIRED	18.7 Weeks	9.2 Weeks	4.6 Weeks	2.3 Weeks

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TABLE 8. OPERATING COSTS FOR OPTION 1 - WITHOUT FLUE GAS SCRUBBING AT SITE 3 (100,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$2,120,180	$1,171,725	$ 795,800	$ 594,550
LABOR	$2,355,174	$1,158,675	$ 805,552	$ 476,928
UTILITIES				
Fuel	$1,774,600	$1,575,166	$1,556,640	$1,556,870
Electricity	$ 79,950	$ 59,000	$ 49,226	$ 49,266
Water	$ 2,802	$ 2,757	$ 2,760	$ 2,760
Wastewater Disposal	$ 4,296	$ 2,757	$ 2,070	$ 1,380
Caustic	N/A	N/A	N/A	N/A
Oversize Debris Disposal	$ 40,349	$ 39,700	$ 40,112	$ 40,112
LABORATORY COSTS	$1,120,800	$ 551,440	$ 368,000	$ 184,000
MISCELLANEOUS SUPPLIES	$ 280,200	$ 137,850	$ 69,000	$ 34,500
CONTINGENCY at 15%	$1,166,753	$ 704,860	$ 553,380	$ 441,055
TOTAL OPERATING COSTS	$8,945,104	$5,403,930	$4,242,580	$3,381,421
TOTAL QUANTITY OF SOIL PROCESSED, TONS	100,000	100,000	100,000	100,000
OPERATING COSTS (UNIT COST BASIS)	$89.50/ton	$54.00/ton	$42.40/ton	$33.80/ton
TOTAL TIME REQUIRED	186.8 Weeks	91.9 Weeks	46.0 Weeks	23.0 Weeks

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TABLE 9. OPERATING COSTS FOR OPTION 2 - WITH FLUE GAS SCRUBBING AT SITE 1 (1,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$ 23,493	$14,050	$10,629	$ 7,757
LABOR	$ 30,145	$16,232	$12,078	$ 6,960
UTILITIES				
Fuel	$ 17,643	$17,140	$19,337	$19,340
Electricity	$ 995	$ 771	$ 734	$ 734
Water	$ 214	$ 197	$ 225	$ 225
Wastewater Disposal	$ 2,396	$ 2,130	$ 2,451	$ 2,451
Caustic	$ 2,043	$ 2,150	$ 2,457	$ 2,443
Oversize Debris Disposal	$ 401	$ 432	$ 498	$ 498
LABORATORY COSTS	$ 11,143	$ 6,000	$ 4,571	$ 2,286
MISCELLANEOUS SUPPLIES	$ 2,786	$ 1,500	$ 857	$ 429
CONTINGENCY at 15%	$ 13,683	$ 9,090	$ 8,076	$ 6,468
TOTAL OPERATING COSTS	$104,902	$69,692	$61,913	$49,591
TOTAL QUANTITY OF SOIL PROCESSED, TONS	1,000	1,000	1,000	1,000
OPERATING COSTS (UNIT COST BASIS)	$104.90/ton	$69.70/ton	$61.90/ton	$49.60/ton
TOTAL TIME REQUIRED	13 days	7 days	4 days	2 days

TABLE 10. OPERATING COSTS FOR OPTION 2 - WITH FLUE GAS SCRUBBING AT SITE 2
(10,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$ 236,555	$129,260	$ 85,560	$ 62,445
LABOR	$ 303,538	$149,334	$ 97,226	$ 56,028
UTILITIES				
Fuel	$ 177,650	$157,688	$155,664	$155,687
Electricity	$ 9,612	$ 7,093	$ 5,911	$ 5,911
Water	$ 2,150	$ 1,812	$ 1,812	$ 1,812
Wastewater Disposal	$ 24,123	$ 19,596	$ 19,734	$ 19,734
Caustic	$ 20,570	$ 19,780	$ 19,780	$ 19,665
Oversize Debris Disposal	$ 4,039	$ 3,974	$ 4,011	$ 4,011
LABORATORY COSTS	$ 112,200	$ 55,200	$ 36,800	$ 18,400
MISCELLANEOUS SUPPLIES	$ 28,050	$ 13,800	$ 6,900	$ 3,450
CONTINGENCY at 15%	$ 133,773	$ 83,631	$ 65,010	$ 52,071
TOTAL OPERATING COSTS	$1,056,260	$641,168	$498,408	$399,214
TOTAL QUANTITY OF SOIL PROCESSED, TONS	10,000	10,000	10,000	10,000
OPERATING COSTS (UNIT COST BASIS)	$105.60//ton	$64.10/ton	$49.80/ton	$39.90/ton
TOTAL TIME REQUIRED	18.7 Weeks	9.2 Weeks	4.6 Weeks	2.3 Weeks

TABLE 11. OPERATING COSTS FOR OPTION 2 - WITH FLUE GAS SCRUBBING AT SITE 3
(100,000 TON SITE)

Description	System A	System B	System C	System D
EQUIPMENT	$ 2,363,020	$1,291,195	$ 855,600	$ 624,450
LABOR	$ 3,032,138	$1,491,721	$ 972,256	$ 560,280
UTILITIES				
Fuel	$ 1,774,600	$1,575,166	$1,556,640	$1,556,870
Electricity	$ 96,015	$ 70,855	$ 59,110	$ 59,110
Water	$ 21,482	$ 18,104	$ 18,124	$ 18,124
Wastewater Disposal	$ 240,972	$ 195,747	$ 197,340	$ 197,340
Caustic	$ 207,348	$ 197,585	$ 197,800	$ 196,650
Oversize Debris Disposal	$ 40,349	$ 39,700	$ 40,112	$ 40,112
LABORATORY COSTS	$ 1,120,800	$ 551,400	$ 368,000	$ 184,000
MISCELLANEOUS SUPPLIES	$ 280,200	$ 137,850	$ 69,000	$ 34,500
CONTINGENCY at 15%	$ 1,376,539	$ 835,398	$ 650,097	$ 520,715
TOTAL OPERATING COSTS	$10,553,463	$6,404,721	$4,984,079	$3,992,151
TOTAL QUANTITY OF SOIL PROCESSED, TONS	100,000	100,000	100,000	100,000
OPERATING COSTS (UNIT COST BASIS)	$105.50/ton	$64.00/ton	$49.80/ton	$39.90/ton
TOTAL TIME REQUIRED	186.8 Weeks	91.9 Weeks	46.0 Weeks	23.0 Weeks

4.1.2 Trucks. The trucks considered in this analysis are 20 yd^3 capacity dump trucks with roll-off box type beds. These type of trucks and roll-off boxes are commonly used for industrial and commercial solid waste collection and transportation. The trucks listed in Tables 12 and 13 will serve two purposes:

(1) They will be used to transport excavated soil to the contaminated soil staging and storage area near the processing site.

(2) They will be used to transport the roll-off boxes of processed soil back to the excavation area for on-site disposal as backfill.

The weekly rental price of $1,000/wk includes the truck and one roll-off box.

4.1.3 Additional roll-off boxes. Additional roll-off boxes are necessary to provide sufficient storage capacity for processed soil analysis prior to disposal. The estimated cost for additional roll-off boxes is $150 per box per week.

4.1.4 Safety equipment. It is assumed that Level "C": safety equipment will be sufficient with Level "B" respiratory protection available, if required. Safety equipment costs are estimated at $50 per man day for disposable Tyvek suits, rubber gloves, rubber overboots, respirator rental, and cartridge replacement. Tables 12 and 13 provide the estimated man days per week for each system and option. The increased man days per week for the larger and more complex systems are because of the number of additional operators who are required. The labor categories are presented in Subsection 4.2.

4.1.5 Trailers. It is assumed that three trailers will be provided for all systems evaluated, including:

(a) Office trailer at $375/week.
(b) Decontamination trailer at $375/week.
(c) Equipment storage trailer at $250/week.

4.1.6 Utility vehicle. The utility vehicle for all systems evaluated is a 1/2-ton capacity 4-wheel drive pick-up at a cost of $350/week.

TABLE 12. EQUIPMENT COSTS ON A WEEKLY BASIS FOR OPTION 1 AT ALL SITES

Description	System A	System B	System C	System D
FRONT END LOADERS (EXCAVATION)				
Quantity/Capacity, yd^3	2 @ 1.0	2 @ 1.5	2 @ 2.25	2 @ 5.0
Max. Production Rate (each), yd^3/hr	60	80	100	185
Weekly Rental Fee	$4,000	$4,800	$5,600	$10,100
TRUCKS (W/ROLL-OFF BOX)				
Quantity/Capacity, yd^3	1 @ 20	1 @ 20	2 @ 20	2 @ 20
Weekly Rental	$1,000	$1,000	$2,000	$2,000
ROLL-OFF BOXES (EXTRAS)				
Quantity/Capacity, yd^3	8 @ 20	12 @ 20	20 @ 20	40 @ 20
Weekly Rental	$1,200	$1,800	$3,000	$6,000
SAFETY EQUIPMENT				
Man days/Week	67	67	98	119
Weekly Cost	$3,350	$3,350	$4,900	$5,950
TRAILERS (OFFICE, DECON. AND STORAGE)				
No. of Trailers	3	3	3	3
Weekly Rental	$1,000	$1,000	$1,000	$1,000
UTILITY VEHICLE				
Quantity/Type	1-Pick-up	1-Pick-up	1-Pick-up	1-Pick-up
Weekly Rental	$350	$350	$350	$350
MONITORING EQUIPMENT				
Quantity/Type	1-OVA or HNu	1-OVA or HNu	1-OVA or HNu	1-OVA or HNu
Weekly Rental	$350	$350	$350	$350
SANITARY FACILITIES				
Quantity	2	2	2	2
Weekly Rental	$100	$100	$100	$100
TOTAL EQUIPMENT COSTS, per week	$11,350	$12,750	$17,300	$25,850
EQUIPMENT UNIT COSTS, per ton (Assuming Operation @ 85% of Design Capacity)	$21.20	$11.70	$7.90	$5.90

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TABLE 13. EQUIPMENT COSTS ON A WEEKLY BASIS FOR OPTION 2 AT ALL SITES

Description	System A	System B	System C	System D
FRONT END LOADERS (EXCAVATION)				
Quantity/Capacity, yd^3	2 @ 1.0	2 @ 1.5	2 @ 2.25	2 @ 5.0
Max. Production Rate (each), yd^3/hr	60	80	100	185
Weekly Rental Fee	$4,000	$4,800	$5,600	$10,100
TRUCKS (W/ROLL-OFF BOX)				
Quantity/Capacity, yd^3	1 @ 20	1 @ 20	2 @ 20	2 @ 20
Weekly Rental	$1,000	$1,000	$2,000	$2,000
ROLL-OFF BOXES (EXTRAS)				
Quantity/Capacity, yd^3	8 @ 20	12 @ 20	20 @ 20	40 @ 20
Weekly Rental	$1,200	$1,800	$3,000	$6,000
SAFETY EQUIPMENT				
Man days/Week	93	93	124	145
Weekly Cost	$4,650	$4,650	$6,200	$7,250
TRAILERS (OFFICE, DECON. AND STORAGE)				
No. of Trailers	3	3	3	3
Weekly Rental	$1,000	$1,000	$1,000	$1,000
UTILITY VEHICLE				
Quantity/Type	1-Pick-up	1-Pick-up	1-Pick-up	1-Pick-up
Weekly Rental	$350	$350	$350	$350
MONITORING EQUIPMENT				
Quantity/Type	1-OVA or HNu	1-OVA or HNu	1-OVA or HNu	1-OVA or HNu
Weekly Rental	$350	$350	$350	$350
SANITARY FACILITIES				
Quantity	2	2	2	2
Weekly Rental	$100	$100	$100	$100
TOTAL EQUIPMENT COSTS, per week	$12,650	$14,050	$18,600	$27,150
EQUIPMENT UNIT COSTS, per ton (Assuming Operation @ 35% of Design Capacity)	$23.60	$12.90	$8.50	$6.20

4.1.7 Monitoring equipment. The monitoring equipment for all systems evaluated is a hand-held portable VOC detector (either an OVA-Flame Ionization Detector or HNu-Photo-Ionization Detector) to provide field identification of contamination hot spots at the excavation site, and for the Site Safety Officer to perform routine VOC monitoring sweeps for personnel protection. The weekly rental rate for one monitoring device is $350/week. It is assumed that stack monitoring equipment will not be required.

4.1.8 Sanitary facilities. Two portable sanitary facilities are included for each system evaluated. The weekly rental cost including clean-out and disposal service is $100/week for both units.

4.2 Labor. Tables 14 and 15 provide a summary of the labor costs on a weekly basis for Option 1 and Option 2, respectively. The job classifications and assumed hours per week are clearly shown in Tables 14 and 15. For the Site Leader, Site Safety Officer, Maintenance Technicians, and Excavation Operators, 60 hour work weeks have been assumed. It is WESTON's experience that field work of this nature will typically require 10 hour days and 6 day weeks. Not accounting for this in the cost estimate will result in unrealistically low labor costs. Shift positions requiring 24 hours per day coverage, 7 days per week are estimated based upon 168 hours per week per shift position (i.e., LTTS operators and scrubber operators). The hourly salary rates assumed (including overheads and fringe benefits) are summarized below:

Job classification	Hourly salary rate including overhead and fringe benefits
Site Leader	$30/hr
LTTS Operators	$18/hr
Scrubber Operators	$18/hr
Site Safety Officer	$20/hr
Maintenance Technicians	$10/hr
Excavation Operators	$18/hr
Contract Mechanic/Electrician	$20/hr
Secretary	$10/hr

4.3 Utilities. Tables 16 and 17 provide a summary of the utility costs on a weekly basis for Option 1 and Option 2, respectively. A brief discussion of the utility costs is presented in the following subsections.

TABLE 14. LABOR COSTS ON A WEEKLY BASIS FOR OPTION 1 AT ALL SITES

Description	System A	System B	System C	System D
SITE LEADER				
Hours/Week	60	60	60	60
Weekly Labor Costs*	$ 1,800	$ 1,800	$ 1,800	$ 1,800
LTTT OPERATORS				
Hours/Week	336	336	504	672
Weekly Labor Costs	$ 6,048	$ 6,048	$ 9,072	$12,096
SCRUBBER OPERATORS				
Hours/Week	N/A	N/A	N/A	N/A
Weekly Labor Costs*	N/A	N/A	N/A	N/A
SITE SAFETY OFFICER				
Hours/Week	60	60	60	60
Weekly Labor Costs*	$ 1,200	$ 1,200	$ 1,200	$ 1,200
MAINTENANCE TECHNICIANS				
Hours/Week	60	60	120	120
Weekly Labor Costs*	$ 600	$ 600	$ 1,200	$ 1,200
EXCAVATION OPERATORS				
Hours/Week	120	120	180	180
Weekly Labor Costs*	$ 2,160	$ 2,160	$ 3,240	$ 3,240
CONTRACT MECHANIC/ELECTRICIAN				
Hours/Week	20	20	30	40
Weekly Labor Costs*	$ 400	$ 400	$ 600	$ 800
SECRETARY				
Hours/Week	40	40	40	40
Weekly Labor Costs*	$ 400	$ 400	$ 400	$ 400
TOTAL LABOR COSTS, per week	$12,608	$12,608	$17,512	$20,736
LABOR UNIT COSTS, per ton (Assuming Operation @ 85% of Design Capacity)	$23.50	$11.60	$ 8.00	$ 4.80

* Labor Costs include overhead and fringe benefits.

TABLE 15. LABOR COSTS ON A WEEKLY BASIS FOR OPTION 2 AT ALL SITES

Description	System A	System B	System C	System D
SITE LEADER				
Hours/Week	60	60	60	60
Weekly Labor Costs*	$ 1,800	$ 1,800	$ 1,800	$ 1,800
LTTT OPERATORS				
Hours/Week	336	336	504	672
Weekly Labor Costs	$ 6,048	$ 6,048	$ 9,072	$12,096
SCRUBBER OPERATORS				
Hours/Week	168	168	168	168
Weekly Labor Costs*	$ 3,024	$ 3,024	$ 3,024	$ 3,024
SITE SAFETY OFFICER				
Hours/Week	60	60	60	60
Weekly Labor Costs*	$ 1,200	$ 1,200	$ 1,200	$ 1,200
MAINTENANCE TECHNICIANS				
Hours/Week	120	120	180	180
Weekly Labor Costs*	$ 1,200	$ 1,200	$ 1,800	$ 1,800
EXCAVATION OPERATORS				
Hours/Week	120	120	180	180
Weekly Labor Costs*	$ 2,160	$ 2,160	$ 3,240	$ 3,240
CONTRACT MECHANIC/ELECTRICIAN				
Hours/Week	20	20	30	40
Weekly Labor Costs*	$ 400	$ 400	$ 600	$ 800
SECRETARY				
Hours/Week	40	40	40	40
Weekly Labor Costs*	$ 400	$ 400	$ 400	$ 400
TOTAL LABOR COSTS, per week	$16,232	$16,232	$21,136	$24,360
LABOR UNIT COSTS, per ton (Assuming Operation @ 85% of Design Capacity)	$30.30	$14.90	$ 9.70	$ 5.60

* Labor Costs include overhead and fringe benefits.

TABLE 16. SUMMARY OF UTILITY COSTS ON A WEEKLY BASIS FOR OPTION 1 AT ALL SITES

Description	System A	System B	System C	System D
FUEL				
Fuel Consumption, Btu/wk	950×10^6	$1,714 \times 10^6$	$3,384 \times 10^6$	$6,769 \times 10^6$
Weekly Fuel Cost, per wk	$9,500	17,140	33,840	67,690
ELECTRICITY				
Demand, kW	50	75	125	250
Consumption, kWh/wk	7.14×10^3	1.07×10^4	1.79×10^4	3.57×10^4
Weekly Electricity Costs	$428	$642	$1,071	$2,142
WATER				
Water Consumption, gal/wk	15×10^3	30×10^3	60×10^3	120×10^3
Weekly Water Cost	$15	$30	$60	$120
WASTEWATER DISPOSAL				
Disposal Requirements, gal/wk	750	1,000	1,500	2,000
Weekly Disposal Costs	$23	$30	$45	$60
CAUSTIC				
Caustic Requirements	N/A	N/A	N/A	N/A
Weekly Caustic Costs	N/A	N/A	N/A	N/A
OVERSIZE DEBRIS DISPOSAL				
Disposal Requirements, tons/wk	27	54	109	218
Weekly Disposal Costs	$216	$432	$872	$1,744
TOTAL UTILITY COSTS, per wk	$10,182	$18,274	$35,888	$71,756
UTILITY UNIT COSTS, per ton (Assuming Operation @ 85% of Design Capacity)	$19.00	$16.80	$16.50	$16.50

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TABLE 17. UTILITY COSTS ON A WEEKLY BASIS FOR OPTION 2 AT ALL SITES

Description	System A	System B	System C	System D
FUEL				
Fuel Consumption, Btu/wk	950×10^6	$1,714 \times 10^6$	$3,384 \times 10^6$	$6,769 \times 10^6$
Weekly Fuel Cost, per wk	$9,500	$17,140	$33,840	$67,690
ELECTRICITY				
Demand, kW	60	90	150	300
Consumption, kWh/wk	8.57×10^3	1.29×10^4	2.14×10^4	4.28×10^4
Weekly Electricity Costs	$514	$771	$1,285	$2,570
WATER				
Water Consumption, gal/wk	115×10^3	197×10^3	394×10^3	788×10^3
Weekly Water Cost	$115	$197	$394	$788
WASTEWATER DISPOSAL				
Disposal Requirements, gal/wk	43×10^3	71×10^3	143×10^3	286×10^3
Weekly Disposal Costs	$1,290	$2,130	$4,290	$8,580
CAUSTIC				
Caustic Requirements, lbs/wk	2.2×10^3	4.3×10^3	8.6×10^3	17.1×10^3
Weekly Caustic Costs	$1,100	$2,150	$4,300	$8,550
OVERSIZE DEBRIS DISPOSAL				
Disposal Requirements, tons/wk	27	54	109	218
Weekly Disposal Costs	$216	$432	$872	$1,744
TOTAL UTILITY COSTS, per wk	$12,735	$22,820	$44,981	$89,922
UTILITY UNIT COSTS, per ton (Assuming Operation @ 85% of Design Capacity)	$23.80	$21.00	$20.70	$20.60

4.3.1 Fuel. This analysis assumes that propane will be burned in both the oil heater and the afterburner. Use of propane allows for ease of operation in remote locations and ensures clean burning and minimization of stack air pollutants. The fuel cost assumed is $\$10.00/10^6$ Btu (which is somewhat conservative). No. 2 fuel oil is currently available at less than $\$7.00/10^6$ Btu which would reduce the fuel costs presented in Tables 14 and 15 by 30 percent.

4.3.2 Electricity. The electricity costs are estimated based upon an energy charge of $0.06/kWh multiplied by the kwh of electricity consumed per week at an 85 percent capacity factor.

4.3.3 Water. The water consumption for Option 2 is based upon water consumed for processed soil cooling, conditioning, dust control and for decontamination of personnel and equipment. The water consumption for Option 2 includes all of the above, plus the water consumption for the scrubbing system. Water costs are estimated based upon $\$1.00$ per 10^3 gallons which assumes the availability of uncontaminated well water. If uncontaminated well water is not available (which is often the case at VOC-contaminated remedial action sites) then uncontaminated water must be trucked in. This may result in water costs an order of magnitude higher. This potential impact is investigated in Section 6, Sensitivity Analysis, of this report.

4.3.4 Wastewater disposal. The wastewater disposal requirements for Option 1 are based upon the disposal of decontamination water at a local municipal wastewater treatment plant within a 50 mile radius of the site. The estimated disposal cost is $\$30$ per 10^3 gallons which includes transportation by 6,000 gallon tanker truck as well as the disposal fee at the wastewater treatment plant. Option 2 includes the above plus the scrubber blowdown water. If the wastewater is unacceptable for disposal at the local municipal wastewater treatment facility, it may require trucking to a permitted hazardous waste treatment facility which again could result in an order of magnitude increase in wastewater disposal costs. This will also be considered in the sensitivity analysis.

4.3.5 Caustic. Caustic consumption is only applicable to Option 2 - With Flue Gas Scrubbing. The caustic costs are estimated based upon a delivered caustic price of $0.50 per pound.

4.3.6 Oversize debris disposal. The oversize debris disposal quantities are based upon 5 percent of the total feed soil quantities. The disposal costs are estimated to be $8 per ton for disposal at a nonhazardous landfill. If the oversize debris must be manifested to a licensed hazardous waste landfill, these disposal costs would be considerably higher. The impact of this situation is investigated in the sensitivity analysis, Section 6.

4.4 Laboratory costs. The laboratory costs are based upon performing all analyses on-site in a mobile laboratory, providing one-day turn-around for processed soil decontamination verification. The cost for rental of the on-site laboratory plus one on-site laboratory technician is $6,000 per week. Due to the larger number of samples to be analyzed, Systems C and D will require a second laboratory technician at an additional estimated cost of $2,000 per week.

4.5 Miscellaneous supplies. Miscellaneous supplies for maintenance, office supplies, and other consumable items is estimated to be $1,500 per week for all systems evaluated.

4.6 Contingency. The contingency is based upon 15 percent of the total operating costs.

5. TOTAL PROJECT COSTS

The objective of this section is to present the total project costs for each of the alternatives evaluated. Tables 18 through 20 provide a summary of this data as follows:

Table no.	Total project cost data summarized
18	Total Project Costs for Site 1 (1,000 ton site)
19	Total Project Costs for Site 2 (10,000 ton site)
20	Total Project Costs for Site 3 (100,000 ton site)

5.1 Option 1 - Without off-gas scrubbing. Figure 9 presents a graphical summary of the total project costs for the range of sites evaluated (i.e., up to 100,000 tons of soil preocessed) for Option 1. Figure 10 presents a similar graphical summary of the project unit costs on a $/ton basis for Option 1.

5.2 Option 2 - With off-gas scrubbing. Figure 11 presents a graphical summary of the total project costs for the range of sites evaluated for Option 2. Figure 12 presents a similar graphical summary of the project unit costs on a $/ton basis for Option 2.

TABLE 18. TOTAL PROJECT COSTS FOR SITE 1
(1,000 TON SITE)

Description	System A	System B	System C	System D
Option 1 - without flue gas scrubbing				
- Total capital costs	$1,132,200	$1,581,200	$2,530,100	$4,641,400
- Total operating costs	$ 88,900	$ 58,800	$ 52,700	$ 42,000
- Total project costs	$1,221,100	$1,640,000	$2,582,800	$4,683,400
- $/ton basis	$ 1,221	$ 1,640	$ 2,583	$ 4,683
- Total time required	13 days	7 days	4 days	2 days
Option 2 - with flue gas scrubbing				
- Total capital costs	$1,300,600	$1,800,200	$2,890,500	$5,107,200
- Total operating costs	$ 104,900	$ 69,700	$ 61,900	$ 49,600
- Total project costs	$1,405,500	$1,869,900	$2,952,400	$5,156,800
- $/ton basis	$ 1,406	$ 1,870	$ 2,952	$ 5,157
- Total time required	13 days	7 days	4 days	2 days

TABLE 19. TOTAL PROJECT COSTS FOR SITE 2
(10,000 TON SITE)

Description	System A	System B	System C	System D
Option 1 - without flue gas scrubbing				
- Total capital costs	$1,132,200	$1,581,200	$2,530,100	$4,641,400
- Total operating costs	$ 895,500	$ 541,000	$ 424,300	$ 338,100
- Total project costs	$2,027,700	$2,122,200	$2,954,400	$4,979,500
- $/ton basis	$ 203	$ 212	$ 295	$ 498
- Total time required	18.7 weeks	9.2 weeks	4.6 weeks	2.3 weeks
Option 2 - with flue gas scrubbing				
- Total capital costs	$1,300,600	$1,800,200	$2,890,500	$5,107,200
- Total operating costs	$1,056,300	$ 641,200	$ 498,400	$ 399,200
- Total project costs	$2,356,900	$2,441,400	$3,388,900	$5,506,400
- $/ton basis	$ 236	$ 244	$ 339	$ 551
- Total time required	18.7 weeks	9.2 weeks	4.6 weeks	2.3 weeks

TABLE 20. TOTAL PROJECT COSTS FOR SITE 3
(100,000 TON SITE)

Description	System A	System B	System C	System D
Option 1 - without flue gas scrubbing				
- Total capital costs	$ 1,132,200	$1,581,200	$2,530,100	$4,641,400
- Total operating costs	$ 8,945,100	$5,403,900	$4,242,600	$3,381,400
- Total project costs	$10,077,300	$6,985,100	$6,772,700	$8,022,800
- $/ton basis	$ 101	$ 70	$ 68	$ 80
- Total time required	186.8 weeks (3.6 years)	91.9 weeks (1.8 years)	46.0 weeks	23.0 weeks
Option 2 - with flue gas scrubbing				
- Total capital costs	$ 1,300,600	$1,800,200	$2,800,500	$5,107,200
- Total operating costs	$10,553,500	$6,404,700	$4,984,100	$3,992,200
- Total project costs	$11,854,100	$8,204,900	$7,784,600	$9,099,400
- $/ton basis	$ 119	$ 82	$ 78	$ 91
- Total time required	186.8 weeks (3.6 years)	91.9 weeks (1.8 years)	46.0 weeks	23.0 weeks

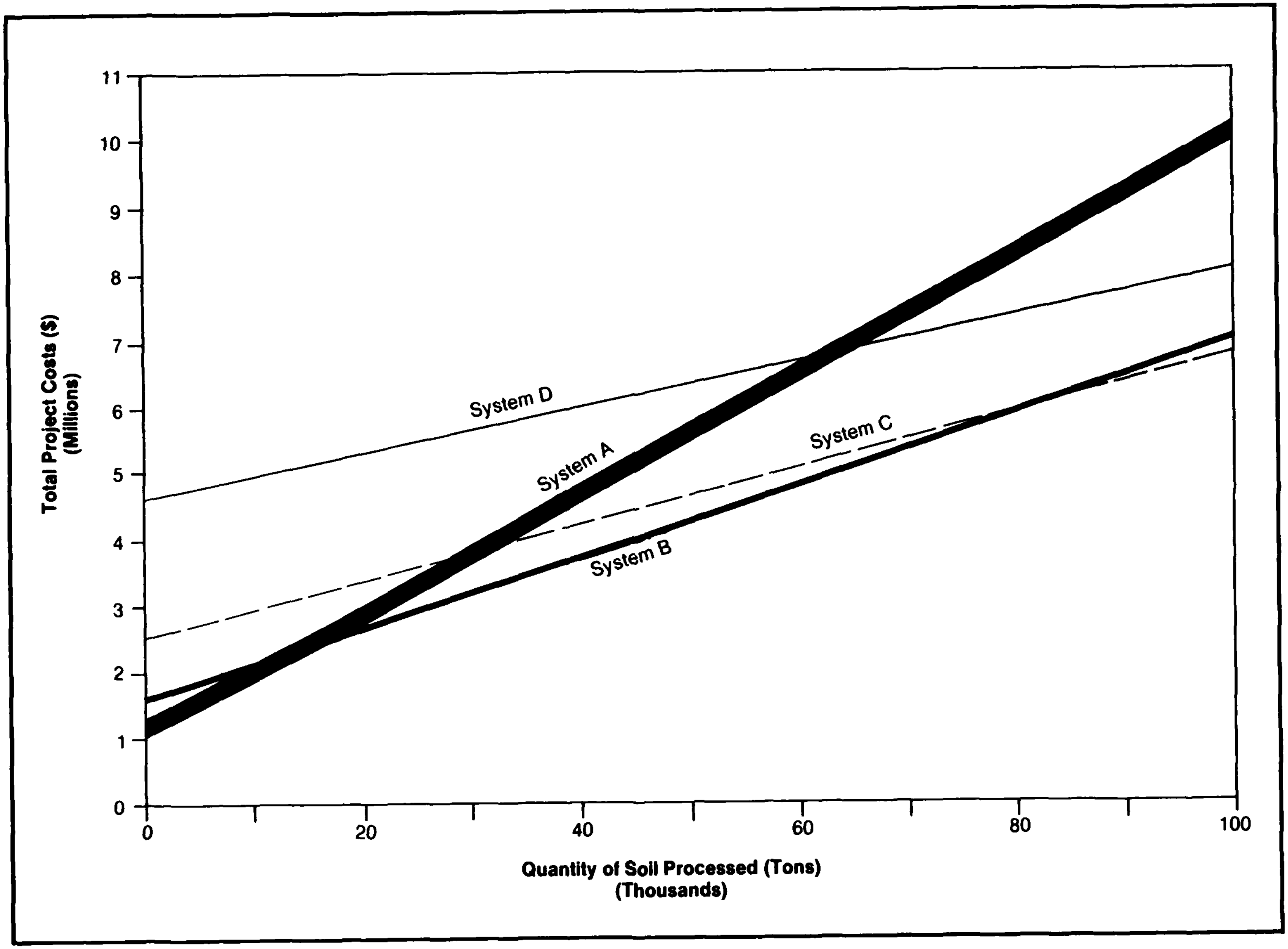

FIGURE 9 TOTAL PROJECT COSTS-OPTION 1

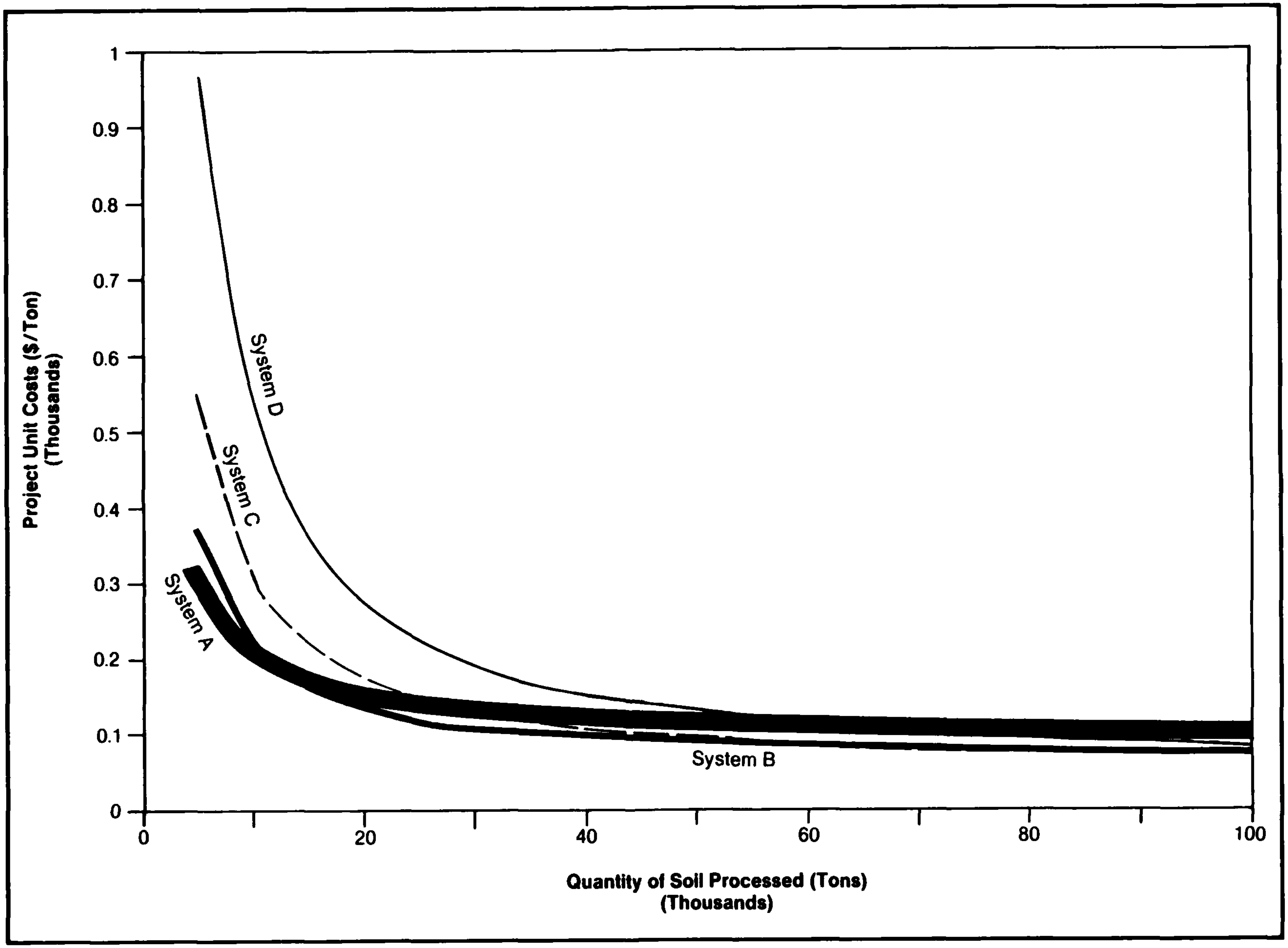

FIGURE 10 PROJECT UNIT COSTS - OPTION 1

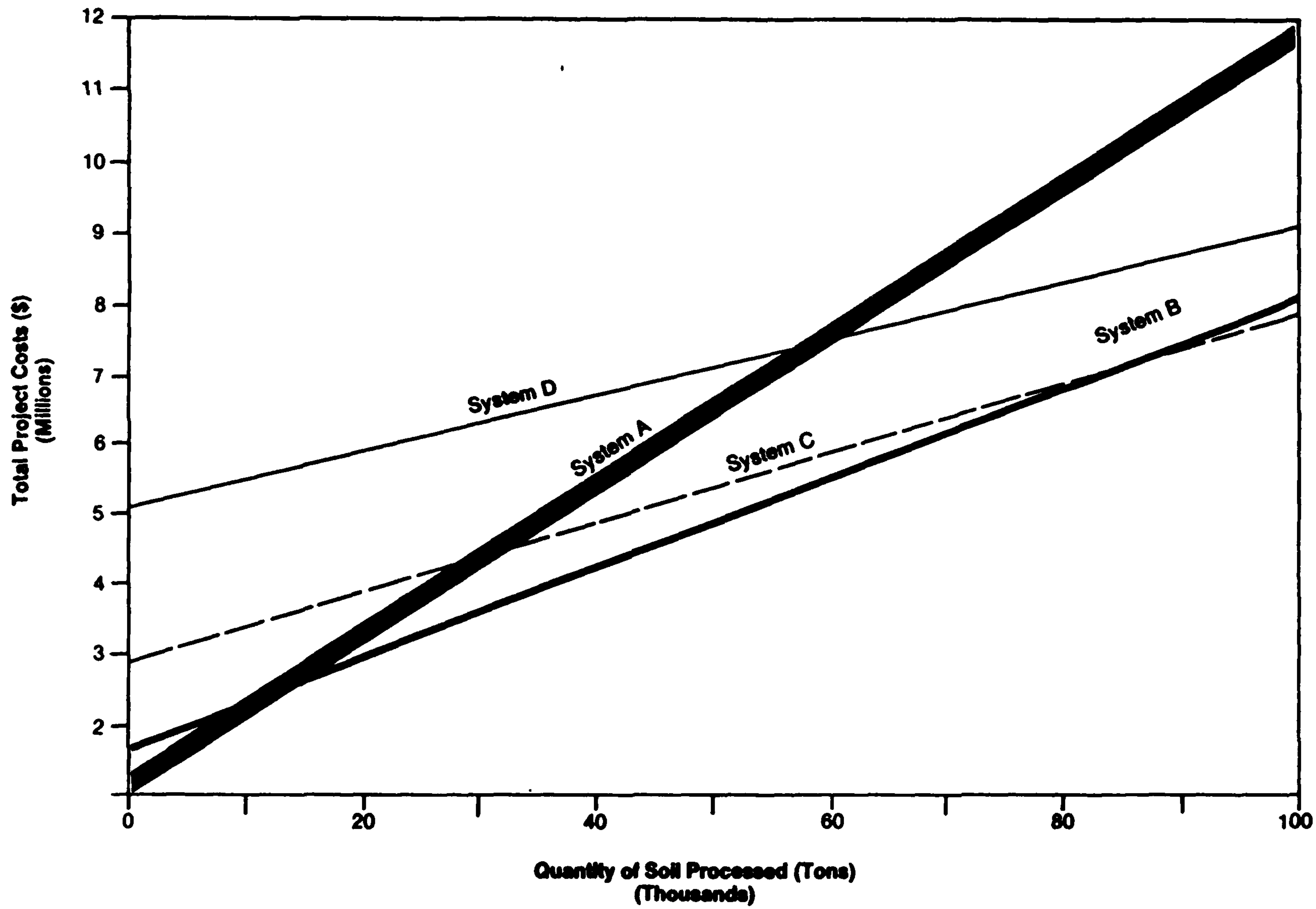

FIGURE 11 TOTAL PROJECT COSTS-OPTION 2

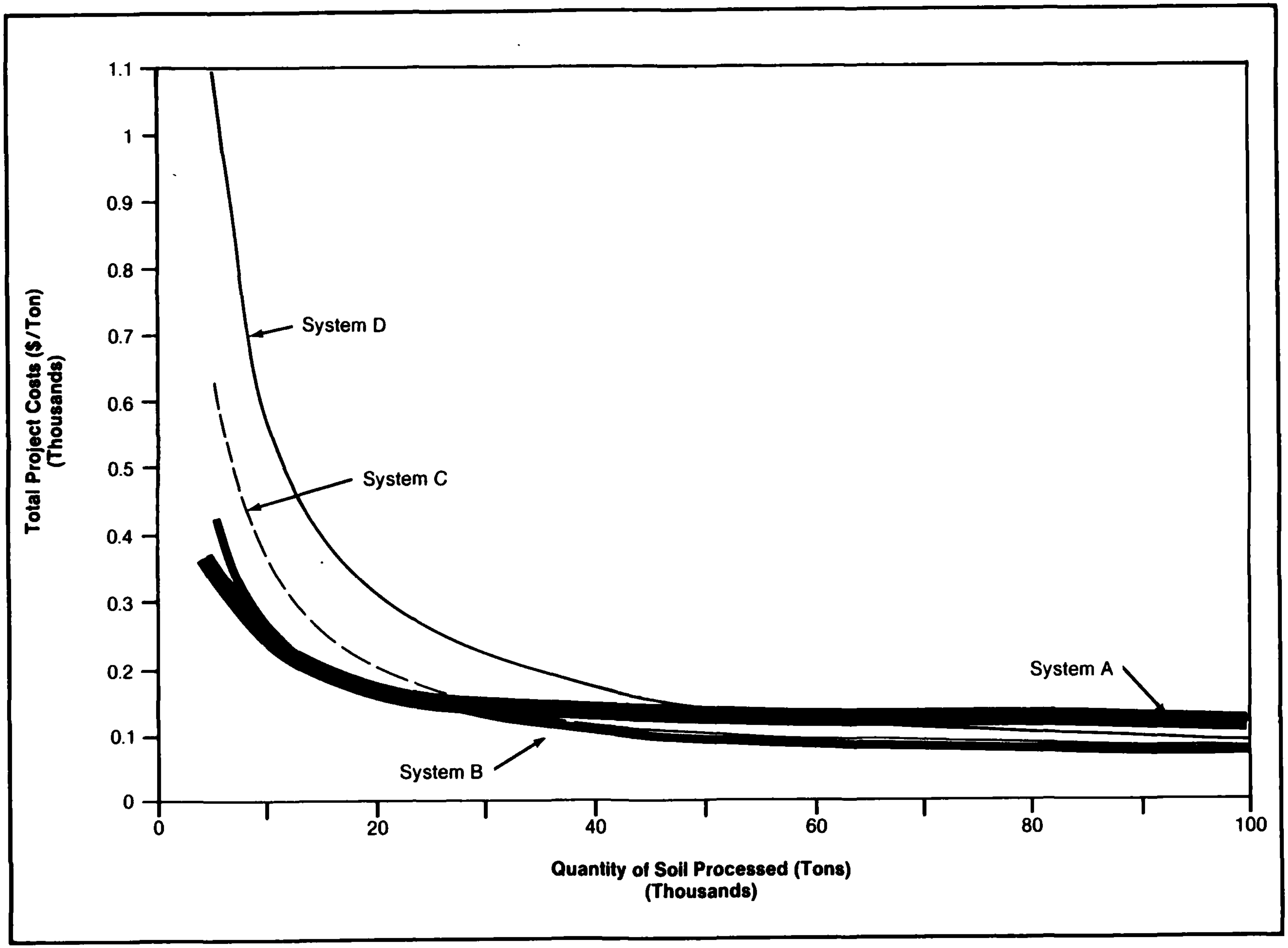

FIGURE 12 PROJECT UNIT COSTS - OPTION 2

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6. SENSITIVITY ANALYSIS

The objective of this section is to analyze the cost data and determine the following:

- What is the sensitivity of total project costs to variations in capital and operating costs?
- Which capital cost factors play a major role in determining the total project capital costs?
- Which operating cost factors play a major role in determining the total project operating costs?
- How will changes in the general economic assumptions affect the results of this analysis?

For ease of discussion the sensitivity analysis is performed on a single "base case" system. The base case system is System B (i.e., single quad-screw system) without flue gas scrubbing (i.e., Option 1). Observations will also be made on how the results of the sensitivity analysis would be affected if the other systems (i.e., Systems A, C, or D) were evaluated.

6.1 Total Project Costs. Figure 13 subdivides the total project costs for System B (Option 1) into capital and operating cost elements. As shown in Figure 13, the capital costs are constant regardless of the quantity of soil processed; whereas, the operating costs are variable and directly related to the quantity of soil processed.

Figure 14 provides similar data for System B (Option 1) except that incremental costs (i.e., $/ton) are presented. On this basis the incremental operating costs are constant (i.e., $37.70 per ton of soil processed); whereas, the incremental capital costs are variable and inversely related to the quantity of soil processed.

The other systems evaluated exhibit similar relationships to those shown for System B in Figures 13 and 14. By comparison System A would have lower capital costs and higher operating costs than shown for System B. Conversely, Systems C and D would have higher capital costs and lower operating costs than shown for System B.

Figures 13 and 14 both demonstrate that for low quantities of soil processed (i.e., small sites) operating costs are relatively insignificant and capital costs are dominant in determining total project costs. For large sites operating costs become dominant. For intermediate size sites (~40,000 tons), the capital and operating costs are about equally significant in determining total project costs.

Figures 15 and 16 provide similar graphs for System B (Option 2).

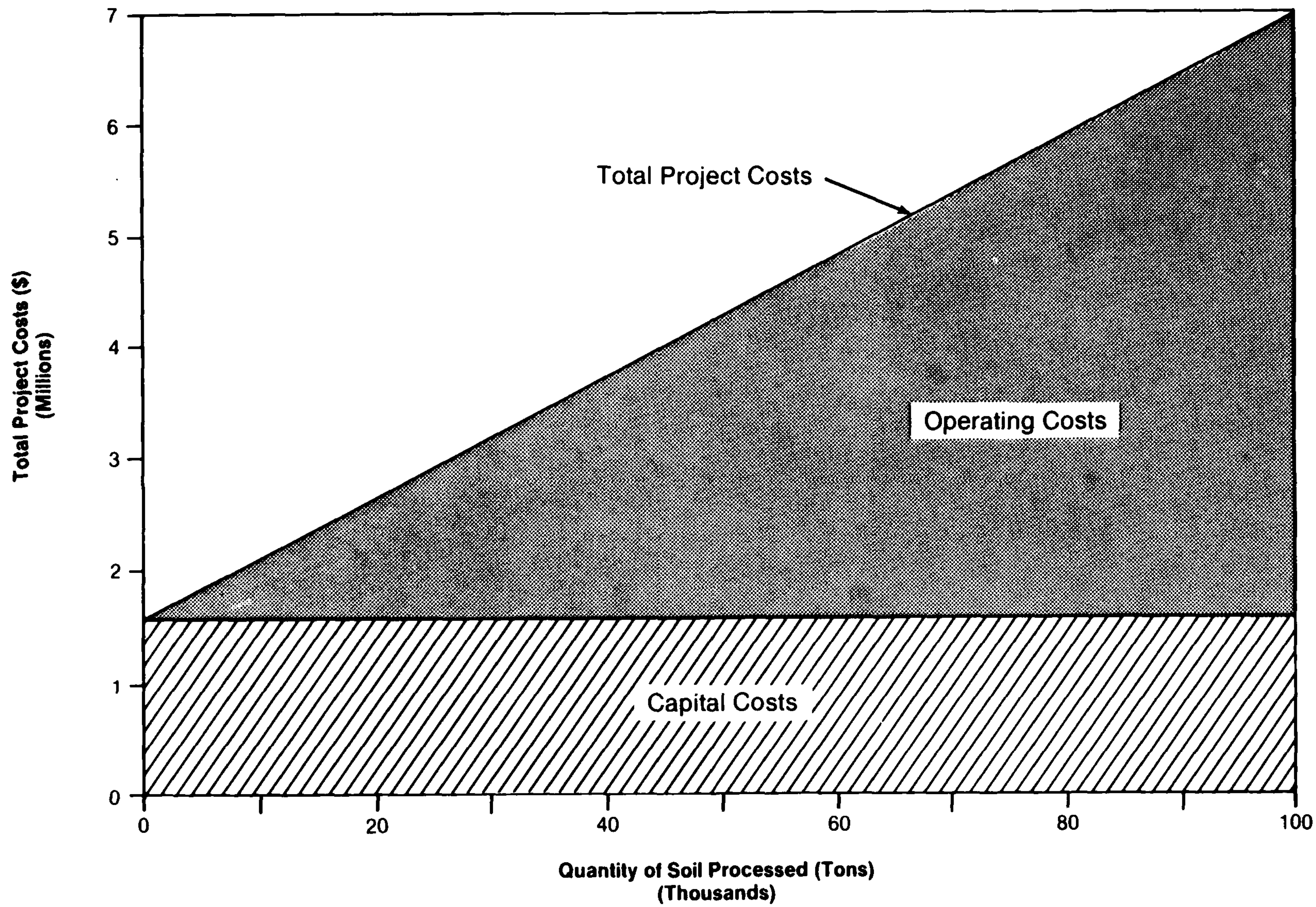

FIGURE 13 SYSTEM B (OPTION 1) TOTAL PROJECT COSTS

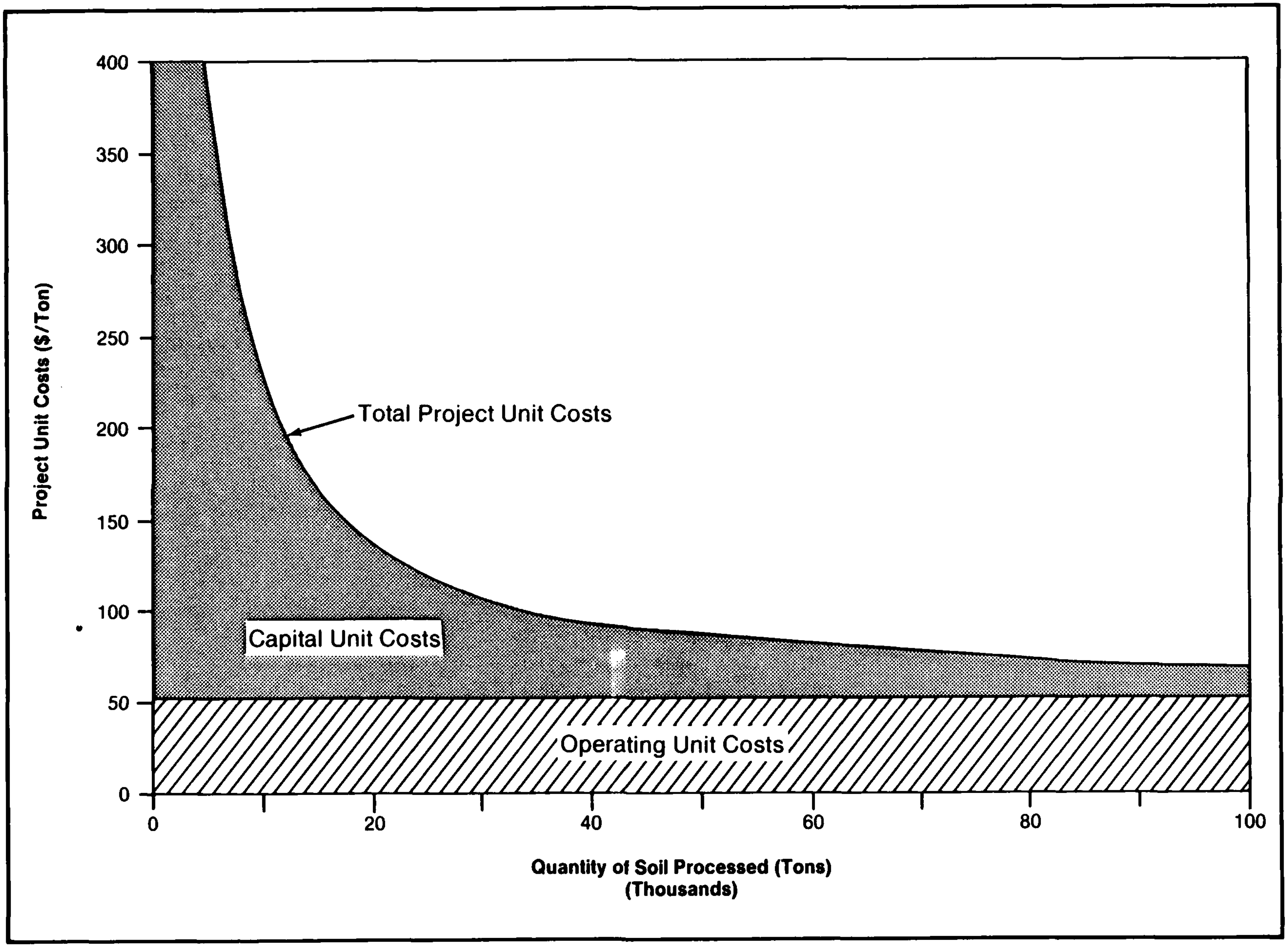

FIGURE 14 SYSTEM B (OPTION 1) UNIT COSTS

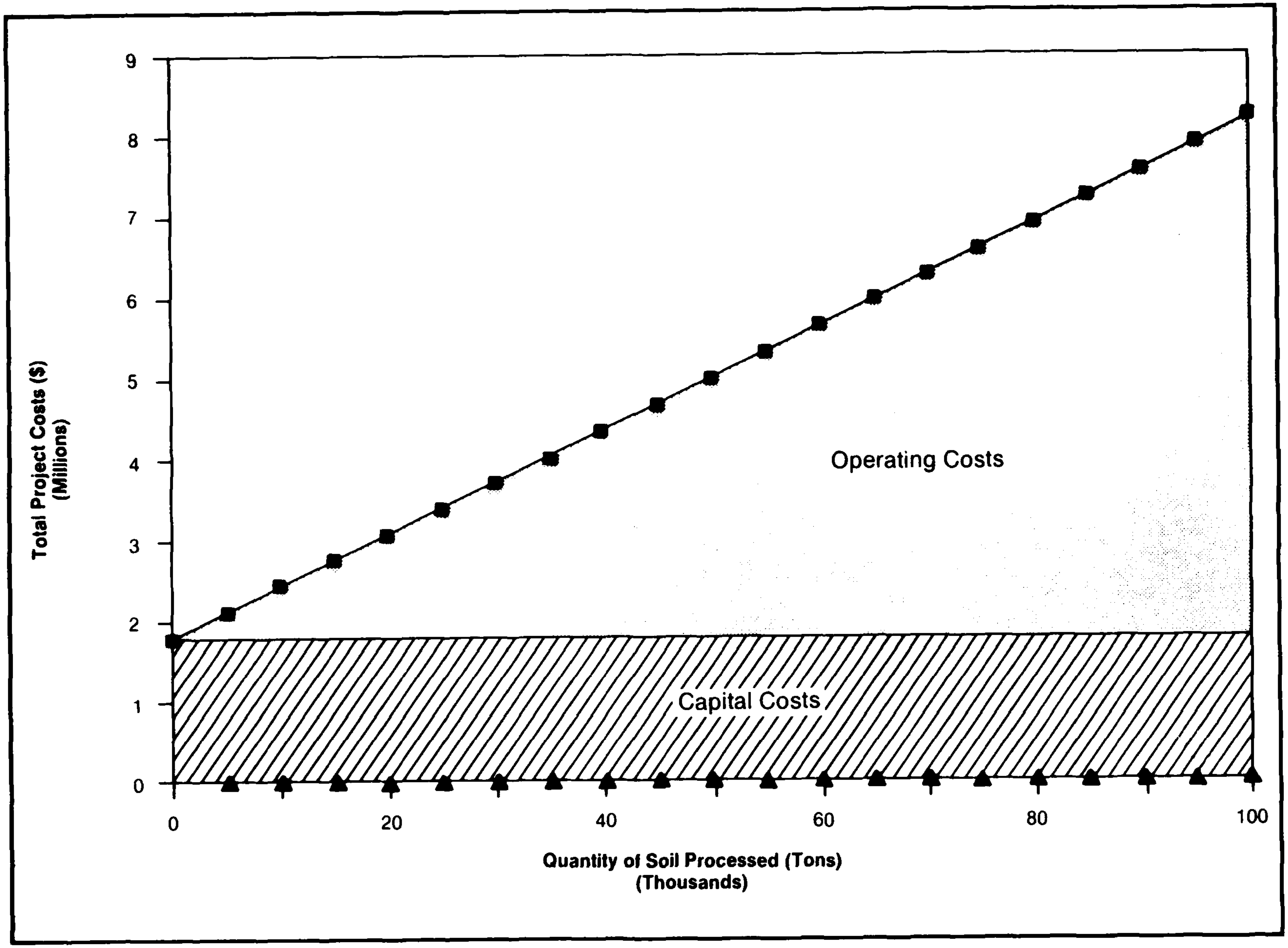

FIGURE 15 SYSTEM B (OPTION 2) TOTAL PROJECT COSTS

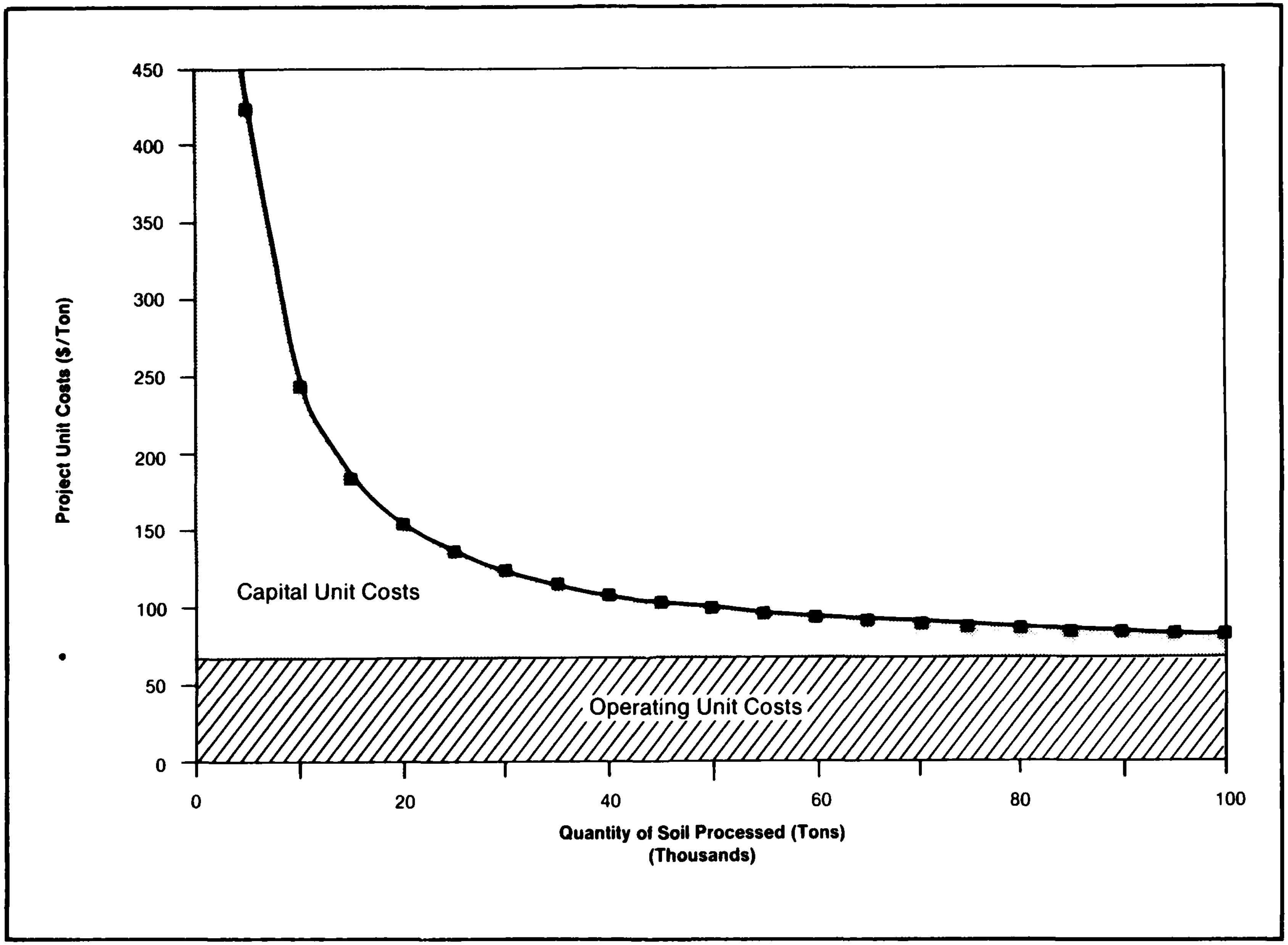

FIGURE 16 SYSTEM B (OPTION 2) UNIT COSTS

6.2 Capital Costs. A sensitivity analysis of capital costs for System B is presented in Table 21. Table 21 presents the itemized estimated capital costs for both the Option 1 (without scrubber) and Option 2 (with scrubber) configurations. In addition, the percentage of the total capital costs represented by each line item is also presented. In general the total direct capital costs (i.e., Equipment Costs F.O.B. Point of Manufacture) represent about 40 percent of the total capital costs. The indirect capital costs account for the remaining 60 percent of the total capital costs.

Four major direct capital cost items account for over 70 percent of the total direct capital costs for both Options 1 and 2:

Major direct capital cost items	Percentage of total direct capital costs	
	Option 1	Option 2
Holo-Flite® Processor	39.1	34.5
Afterburner	15.7	13.8
Feed System	14.4	12.7
Piping and Electrical	12.0	12.0
Total	81.2	73.0

Since these costs are based on vendor quotes, confidence in these estimates is relatively high. The reason for the differences in Options 1 and 2 above are due to the scrubbing system which results in an overall increase in direct capital costs of about 14 percent. Excluding the contingency, three major indirect capital cost items account for over 70 percent of the total indirect capital costs:

TABLE 21. SENSITIVITY ANALYSIS OF CAPITAL COSTS FOR SYSTEM B

Description	System B w/o Scrubber (Option 1)		System B w/scrubber (Option 2)	
	Estimated capital costs ($)	Percentage of total capital costs	Estimated capital costs ($)	Percentage of total capital costs
Direct capital costs				
Holo-Flight® Processor(s)	$ 250,000	15.8	$ 250,000	13.9
Hot oil system	$ 58,000	3.7	$ 58,000	3.2
Feed system	$ 91,900	5.8	$ 91,900	5.1
Processed soil system	$ 11,100	0.7	$ 11,100	0.6
Afterburner	$ 100,000	6.3	$ 100,000	5.6
Flue gas scrubbing system	N/A	N/A	$ 69,200	3.9
Piping and electrical	$ 76,700	4.9	$ 87,000	4.8
Instrumentation and controls	$ 51,100	3.2	$ 58,000	3.2
Total direct capital costs	$ 638,800	40.4	$ 725,200	40.3
Indirect capital costs				
Site preparation/ mobilization	120,000	7.6	$ 130,000	7.2
Construction/erection/ installation	156,900	9.9	$ 186,300	10.3
Engineering	76,700	4.9	$ 87,000	4.8
Permits	150,000	9.5	$ 150,000	8.3

(continued next page)

TABLE 21. (CONTINUED)

Description	System B w/o Scrubber (Option 1) Estimated capital costs ($)	System B w/o Scrubber (Option 1) Percentage of total capital costs	System B w/scrubber (Option 2) Estimated capital costs ($)	System B w/scrubber (Option 2) Percentage of total capital costs
Indirect capital costs (continued)				
Start-up and training	107,300	6.8	$ 136,400	7.6
Spare parts	31,900	2.0	$ 36,300	2.0
Freight	15,000	0.9	$ 21,000	1.2
Site closure/ demobilization	78,400	5.0	$ 93,200	5.2
Contingency	206,200	13.0	$ 234,800	13.1
Total indirect capital costs	942,400	59.6	$1,075,000	59.7
TOTAL CAPITAL COSTS	1,581,200	100.0	$1,800,200	100.0

Major indirect capital cost items	Percentage of total operating costs (excluding contingency) Option 1	Option 2
Construction/Erection/Installation	21.3	22.2
Permits	20.4	17.9
Site Preparation/Mobilization	16.3	15.5
Start-Up and Training	14.6	16.2
Total	72.6	71.8

The construction/erection/installation and start-up and training are conservative estimates and the confidence in these estimates is relatively high. The permitting and site preparation/mobilization will be very site-specific and dependent on regulatory requirements. Therefore, these costs could be widely variable.

6.3 Operating Costs. To perform a sensitivity analysis of operating costs, the first step is to eliminate the impact of site size from the evaluation. This is valid since the unit operating costs (on a $/ton basis) are constant regardless of site size or quantity of soil to be processed. For ease of evaluation, weekly operating costs were selected for this analysis since these operating costs were previously developed in Tables 12 through 17. Table 22 presents the itemized estimated weekly operating costs for both the Option 1 and Option 2 configuration. In addition, the percentage of total operating costs represented by each line item is also presented.

Excluding the contingency, three major operating cost items account for approximately 70 percent of the total operating costs:

Major indirect capital cost items	Percentage of total operating costs (excluding contingency) Option 1	Option 2
Equipment	21.7	20.1
Labor	21.4	23.3
Fuel	29.2	24.6
Total	72.3	68.0

TABLE 22. SENSITIVITY ANALYSIS OF WEEKLY OPERATING COSTS FOR SYSTEM B

Operating costs	System B w/o scrubber (Option 1) Estimated weekly operating costs ($/week)	System B w/o scrubber (Option 1) Percentage of total operating costs	System B w/ scrubber (Option 2) Estimated weekly operating costs ($/week)	System B w/ scrubber (Option 2) Percentage of total operating costs
Equipment	12,750	21.7	14,050	20.1
Labor	12,608	21.4	16,232	23.3
Utilities				
- Fuel	17,140	29.2	17,140	24.6
- Electricity	642	1.1	771	1.1
- Water	30	0.05	197	0.3
- Wastewater Disposal	30	0.05	2,130	3.1
- Caustic	N/A	N/A	2,150	3.1
- Oversize Debris Disposal	432	0.7	432	0.6
Laboratory Costs	6,000	10.2	6,000	8.6
Miscellaneous Supplies	1,500	2.6	1,500	2.2
Contingency	7,670	13.0	9,090	13.0
Total weekly operating costs	$58,802/wk	100.0	$69,692/wk	100.0
Total weekly quantity of soil processed	1,089 tons/wk		1,089 tons/wk	
Operating unit costs ($/ton basis)	$54.00/ton		$64.00/ton	

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The labor costs and fuel costs are based on conservative estimates and equipment costs are based on WESTON's current remedial action experience. Therefore, confidence in these estimates are relatively high.

6.4 General economic assumptions. Three major assumptions were made in this analysis that significantly impact the total project costs:

(1) Soil Moisture Content 20%
(2) Soil Discharge Temperature .... 400°F
(3) System Availability 85%

All three of these assumptions directly impact the total time required to perform the remedial action project. Therefore, they will not impact the capital costs but will directly impact the operating costs.

6.4.1 Moisture content. The feed soil moisture content assumed in this analysis is 20 percent, which is typical based on WESTON's experience regarding excavated soil from unsaturated zones above the groundwater table. Table 1 presents the processing data corresponding to 30 percent moisture content soil. In order to achieve the 400°F discharge temperature with the increased moisture content, an increased residence time (i.e., approximately 40 percent longer) is required. This effectively reduces the processing rate by about 40 percent. Since operating costs (in $/week) are directly related to processing rate, a 10 percent increase in soil moisture content from 20 percent to 30 percent will result in an increase in total operating costs of approximately 40 percent. Correspondingly, a decrease in soil moisture content will result in a significant decrease in total operating costs. As stated previously, capital costs will not be affected by variations in soil moisture content. Figure 17 illustrates the impact of 30 percent soil moisture content upon the total project costs for System B (Option 1).

6.4.2 Soil discharge temperature. The soil discharge temperature assumed in this analysis is 400°F. This is a conservative estimate since 400-450°F is the maximum practical soil discharge temperature due to the maximum temperature limitation of the heating oil. For soils contaminated with relatively low boiling point volatile organic compounds considerably lower soil discharge temperatures may be acceptable. This would allow a reduced soil residence time and corresponding increases in soil feed rate. The net effect would be to substantially reduce total operating costs.

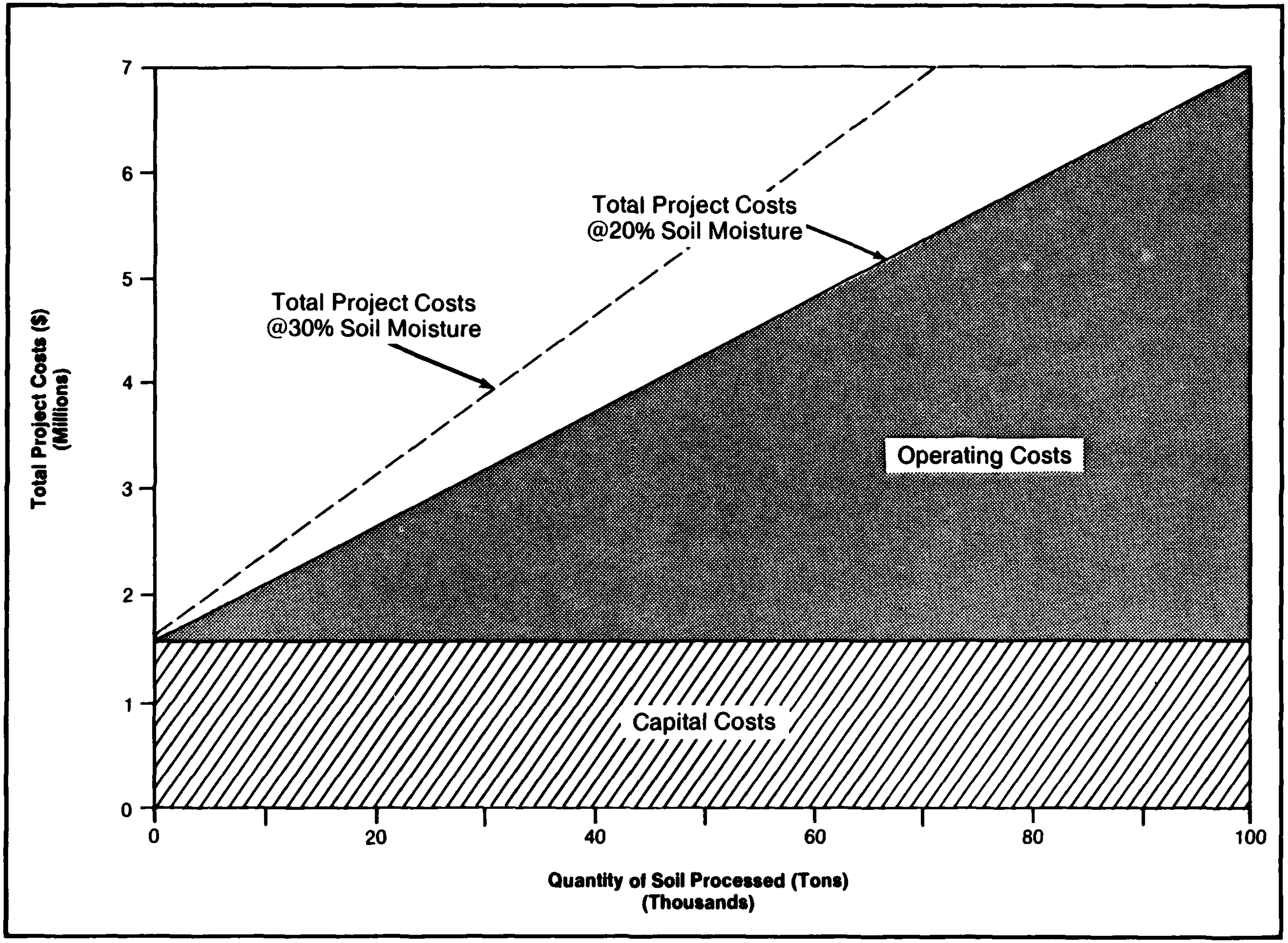

FIGURE 17 SENSITIVITY OF SYSTEM B (OPTION 1) TOTAL PROJECT COSTS TO SOIL MOISTURE CONTENT

6.4.3 System availability. System availability, as used in this analysis, is defined as the equivalent percentage of time that the system is assumed to be operational at the rated design capacity. This includes downtime as well as periods of operation at less than the rated design capacity. The overall system availability assumed in this analysis is 85 percent. This means that the total time required to process a given number of tons is calculated in this manner.

$$\text{Total time required (in hours)} = \frac{\text{No. of tons to be processed}}{\text{Soil processing rate (tons/hr)}} \times 0.85$$

This is consistent with WESTON's experience on the availability of similar types of systems. Decreases in system availability will result in increased total operating costs. Capital costs are not affected by variations in system availability.

6.5 <u>Equipment salvage value</u>. No credit was assumed in this analysis for equipment salvage value at the end of the project life. This approach significantly increases the total project costs for the small sites (i.e., 1,000 tons and 10,000 tons sites) evaluated. Realistically, at least 50 percent of the direct capital costs should be recoverable costs for the turnkey contractor as salvage value for equipment to be used at a subsequent site. For System B without the scrubber this would result in a salvage value of approximately $319,000 or approximately 20 percent of the total capital costs.

6.6 <u>Procurement and contracting costs</u>. Depending on the method of procurement and contracting (i.e., government owned/government operated, government owned/contractor operated, turn-key contractor owned and operated, etc.) additional costs will be incurred above and beyond those identified in this report. Identifying and estimating these costs is beyond the scope of this report.

WESTON
MANAGERS DESIGNERS/CONSULTANTS

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions.

1. Regardless of whether a flue gas scrubbing system is required or not, System B is the most economical system evaluated for sites with 15,000 to 80,000 tons of soil to be processed.
2. System A was somewhat less expensive than System B for sites smaller than 10,000 tons of soil. However, processing costs were in excess of $200 per ton for these smaller sites.
3. System C was somewhat less expensive than System B for sites larger than 85,000 tons of soil.
4. In general, if a flue gas scrubbing system is required, the total capital costs will increase by 10 percent to 15 percent and the operating costs will increase by 15 percent to 20 percent.
5. The sensitivity analysis yielded these conclusions:

   - Direct capital costs represent about 40 percent of the total capital costs. Confidence in these estimates is high since they are based on vendor quotes.
   - Indirect capital costs represent about 60 percent of the total capital costs. Confidence in these estimates is also high except for permitting and site preparation/mobilization which are site-specific and dependent upon regulatory requirements.
   - Operating costs are estimated based on conservative assumptions, and confidence in these estimates is high.
   - Soil moisture content and soil feed rate are very significant parameters affecting operating costs.
   - Equipment salvage value (assumed to be "zero" for this analysis) is a very significant parameter affecting capital costs.
   - Procurement and contracting costs (not considered in this analysis) may significantly impact total project costs.

7.2 Recommendations.

1. A Technical Data Package (performance oriented) should be developed for System B. This is the most cost-effective system for the range of sites from 15,000 to 80,000 tons. The Technical Data Package should include flue gas scrubbing (if required).

2. A survey/literature search of sites targeted for remedial action under the Installation Restoration Program should be performed to determine if technical data packages for smaller (System A) or larger (System C) systems are justified.
3. To further refine operating costs, testing should be performed on a wide variety of uncontaminated soil types and moisture contents to establish an accurate data base for heat transfer coefficients and soil processing rates. This testing could be performed at the Joy Manufacturing Company test facility in Colorado Springs, Colorado, at a nominal cost and with no permitting requirements.
4. Continue economic evaluation to identify and estimate the appropriate procurement and contracting costs.

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