OPERATING COST GUIDELINES FOR BENCHMARKING DOE THERMAL TREATMENT SYSTEMS FOR LOW-LEVEL MIXED WASTE

R. Salmon
S. L. Loghry
W. H. Hermes

NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Date Published: November 1994

Prepared for the
Center for Waste Management
Energy Systems Waste Management Organization

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6495
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ACKNOWLEDGMENTS

The authors would like to thank a number of persons for their useful contributions and suggestions made during the preparation of this report. S. P. N. Singh, S. M. Crosley, J. T. Shor, and M. I. Morris provided flowsheets, data, and references on the Oak Ridge K-1435 Toxic Substances Control Act (TSCA) Incinerator and on other technologies, F. L. Perez provided the backup data on the TSCA Incinerator FY-1994 budget, and S. P. N. Singh provided considerable information on the relationship between regulatory requirements and the costs of sampling and analysis. R. R. Kimmitt and H. P. Wayland participated in the review of the manuscript and provided a number of useful comments.

CONTENTS

	<u>Page</u>
ACKNOWLEDGMENTS	iii
ABSTRACT	vii
1. INTRODUCTION	1
1.1 OBJECTIVE	1
2. THE BENCHMARKING PROCESS	1
3. OPERATING COSTS OF THE TSCA MIXED-WASTE INCINERATOR	2
3.1 THE K-1435 TSCA INCINERATOR FY-1994 BUDGET	3
3.2 TSCA INCINERATOR PLANT OPERATIONS COSTS	3
3.2.1 Costs of Labor and Supervision	8
3.2.2 Materials, Supplies, and Laundry Service	9
3.2.3 Utility Costs	10
3.2.4 Unit Costs of Utility Services	10
3.3 TSCA INCINERATOR COSTS OF SAMPLING AND ANALYSIS	10
3.3.1 Regulatory Requirements for the K-1435 TSCA Incinerator	12
3.3.2 Detailed Cost Experience for the K-1435 TSCA Incinerator	13
3.4 MONITORING	17
3.5 MAINTENANCE	19
3.6 PROGRAM MANAGEMENT AND SUPPORT	22
3.7 ADMINISTRATIVE	22
3.8 ENVIRONMENTAL COMPLIANCE	22
3.9 TECHNICAL SUPPORT	24
4. OPERATING COST GUIDELINES FOR OTHER TECHNOLOGIES	24

4.1	BASIS AND SCOPE	24
4.2	GUIDELINES FOR PLANT OPERATIONS COSTS	25
4.2.1	Labor and Supervision Costs for Other Technologies	25
4.2.2	Materials and Supplies for Other Technologies	26
4.2.3	Utility Costs for Other Technologies	27
4.3	SAMPLING AND ANALYSIS COSTS	27
4.4	MONITORING COSTS FOR OTHER TECHNOLOGIES	28
4.5	MAINTENANCE COSTS OF OTHER TECHNOLOGIES	29
4.6	PROGRAM MANAGEMENT AND SUPPORT COSTS	30
4.7	ADMINISTRATIVE COSTS FOR OTHER TECHNOLOGIES	30
4.8	ENVIRONMENTAL COMPLIANCE COSTS	30
4.9	TECHNICAL SUPPORT COSTS FOR OTHER TECHNOLOGIES	31
4.10	SUMMARY OF RECOMMENDED GUIDELINES	31
5.	CONCLUSIONS	34
6.	REFERENCES	35

ABSTRACT

This report presents guidelines for estimating operating costs for use in benchmarking U.S. Department of Energy (DOE) low-level mixed waste thermal treatment systems. The guidelines are based on operating cost experience at the DOE Toxic Substances Control Act (TSCA) mixed waste incinerator at the K-25 Site at Oak Ridge. Procedures for estimating capital costs are not addressed.

1. INTRODUCTION

1.1 OBJECTIVE

A previous report described a benchmarking process for use in the evaluation of proposed technologies for the thermal treatment of U.S. Department of Energy (DOE) low-level mixed waste (LLMW) (Hoffmann et al. 1994). A systematic procedure was given for benchmarking (evaluating) proposed technologies. This procedure included economic criteria such as capital and operating costs and gave specific guidance as to the types of costs required for use in the benchmarking procedure. Because operating costs depend, to a considerable extent, on actual operating experience, it was felt that a set of actual operating costs, applicable within a DOE framework, would be useful as general guidelines for developing operating costs for various technologies under consistent criteria. Operating costs developed in this manner could then be used as part of the benchmarking process with confidence that they had been developed on a uniform basis. The objective of this work was to use the operating costs experienced at the DOE Toxic Substances Control Act (TSCA) LLMW Incinerator at Oak Ridge to develop such guidelines. In presenting these guidelines, it should be made clear at the outset that it is not the intention of this report to present operating cost estimates for new technologies, but only guidelines for estimating such costs. Guidelines for the estimation of capital costs are beyond the scope of this report and are not addressed.

2. THE BENCHMARKING PROCESS

The benchmarking process (Hoffmann et al. 1994) is a structured process for the evaluation of the performance and costs of LLMW treatment technologies. For such technologies, the benchmarking process specifies the following five categories of evaluation criteria: (1) operation and design, (2) personnel health and safety, (3) economics, (4) product quality, and (5) environmental quality. A detailed analysis was given of the manner in which each of these criteria should be taken into account in

the evaluation of process performance and cost. This report focuses on the third of these criteria, economics, and, in particular, on the estimation of operating costs.

It is fundamental to the benchmarking process that cost is only one factor in the evaluation of LLMW treatment technologies. This is always true when evaluating processes that do not achieve identical results in terms of product quality, environmental quality (i.e., control of emissions), and feedstock versatility (i.e., range of waste types that the process is capable of handling). Each of these factors is potentially capable of outweighing a cost disadvantage in the overall evaluation process. These facts should be kept in mind when considering capital and operating costs.

3. OPERATING COSTS OF THE TSCA MIXED-WASTE INCINERATOR

The total annual operating cost of the TSCA Incinerator is about \$25 million. This can be broken down into eight functional areas: plant operations, sampling and analysis, maintenance, technical support, administrative, monitoring, program management and support, and environmental compliance. Two previous papers have studied these costs in some detail. The first was a review of the TSCA Incinerator FY-1994 budget that included an analysis of costs in each of the eight functional areas (Jacobs 1994). The second was an analysis of the impacts of DOE Orders on the costs and quality of operations in each area (Trischman et al. 1994). References to the impacts of DOE Orders should not be taken as a criticism. On the contrary, these Orders add considerable assurance as to the quality of operations and to the uniformity with which this same degree of high quality is applied to all technologies.

For the present study, it was desired to relate the operating costs in each of the eight functional areas to the technical parameters of plant operations. Backup data for the FY-1994 budget were obtained from the TSCA Incinerator project staff and used as input to this effort.

3.1 THE K-1435 TSCA INCINERATOR FY-1994 BUDGET

Table 1 shows the summary table of the FY-1994 Bottoms-Up Budget for the Oak Ridge K-1435 TSCA Incinerator, as proposed before making the final revisions agreed to during the budget reconciliation process. A "bottoms-up" budget is produced by starting at zero dollars and adding up the estimated costs required to achieve the goals set for the coming fiscal year, based on past experience. The summary table shows the various cost elements of the estimated spending plan for FY-1994, based on a feed rate of about 4.25 million lb/year of LLMW liquids. The FY-1994 Bottoms-Up Budget includes backup data showing detailed calculations of the various cost elements at feed rates of 3.5 and 5.0 million lb/year. The budget summary (Table 1) was based on the average of these feed rates, plus minor revisions.

Table 2 was produced by using the backup data of the FY-1994 budget to calculate the operating costs at feed rates of 3.5 and 5.0 million lb/year and then using the average of these to obtain the costs at 4.25 million lb/year. This column agrees fairly well with the summarized costs of the preliminary FY-1994 budget, which is shown in Table 1. The differences occurred because of the minor budget revisions already mentioned, but these differences are small enough to be unimportant. The preliminary budget summaries shown in Tables 1 and 2 both agree fairly well with the final budget summary used in the Trischman paper, which shows a total of \$25,014,000. Again, differences are present because of revisions that occurred during the budget-reconciliation process; these differences are not significant in the context of this report.

3.2 TSCA INCINERATOR PLANT OPERATIONS COSTS

Plant operations costs account for about 35% of the annual operating budget. The costs listed in Tables 1 and 2 as "plant operations" consist of four items: (1) labor and supervision, (2) materials and supplies, (3) laundry service, and (4) utilities. Table 3 summarizes and details the first three of these items. Table 4 summarizes and details the fourth item, utilities. The details are based on the backup data in the budget document.

Table 1. TSCA incinerator annual operating costs per FY-1994 budget plan^a

Functional area	Cost, \$/year ^b
Plant operations	\$ 8,881,000
Sampling and analysis	5,506,000
Monitoring	1,141,000
Maintenance	4,289,000
Program management and support	909,000
Administrative	1,267,000
Environmental compliance	701,000
Technical support	2,566,000
Total	\$25,260,000

^aBased on data in E. D. Crawford's TSCA Incinerator—FY-1994 Bottoms-Up Budget, September 1993.

^bCosts are based on a feed rate of 4.25 million lb/year.

Table 2. TSCA Incinerator annual operating costs^a

Functional area	Costs, \$/year		
	@ 3.5×10^6 lb/year	@ 5.0×10^6 lb/year	@ 4.25×10^6 lb/year ^b
Plant operations	8,478,574	9,233,409	8,855,992
Maintenance	4,266,826	4,307,699	4,287,262
Sampling and analysis	4,920,460	6,018,707	5,469,584
Monitoring	1,141,097	1,141,097	1,141,097
Program management and support	908,613	908,613	908,613
Administrative	1,266,647	1,266,647	1,266,647
Environmental compliance	701,369	701,369	701,369
Technical support	2,566,304	2,566,304	2,566,304
Total annual operating costs	24,249,890	26,143,845	25,196,868

^aBased on data in E. D. Crawford's TSCA Incinerator—FY-1994 Bottoms-Up Budget, September 1993.

^bAverage of 3.5 and 5.0 million lb/year.

Table 3. TSCA Incinerator: details of plant operations costs^a

Cost element	Costs, \$/year		
	@3.5 × 10 ⁶ lb/year	@5.0 × 10 ⁶ lb/year	@4.25 × 10 ⁶ lb/year
Labor and supervision			
Operators (25)	1,567,508	1,567,508	1,567,508
Supervisors (6)	485,646	485,646	485,646
Staff (19)	1,302,081	1,302,081	1,302,081
Total labor and supervision	3,355,235	3,355,235	3,355,235
Fringe (approximately 31%)	1,033,412	1,033,412	1,033,412
Total labor, supervision, and fringe	4,388,647	4,388,647	4,388,647
Materials and supplies			
General materials and supplies	141,893	169,381	155,637
Additional supplies for outages	64,850	64,850	64,850
Other materials ^b	220,815	315,450	268,132
Total materials and supplies	427,558	549,681	466,619
Laundry service ^c	106,190	106,190	106,190
Total	4,922,395	5,044,518	4,961,456

^aBased on data in E. D. Crawford's TSCA Incinerator—FY-1994 Bottoms-Up Budget, September 1993.

^bOther materials are materials consumed by the process; quantities consumed are directly proportional to throughput.

^cLaundry costs are independent of feed rate in the range 3.5–5.0 million lb/year.

Table 4. TSCA Incinerator: annual utilities costs^a

Utility service	Costs, \$/year		
	@ 3.5×10^6 lb/year	@ 5.0×10^6 lb/year	@ 4.25×10^6 lb/year
Nitrogen	784,114	1,120,164	952,139
Fuel gas	939,332	939,332	939,332
Steam	690,578	986,540	838,559
Air	675,172	675,172	675,172
Electricity	264,009	264,009	264,009
Sanitary water	120,194	120,194	120,194
Sewage disposal	34,853	34,853	34,853
Sanitary waste	48,625	48,628	48,628
Total	3,556,180	4,188,892	3,872,536

^aBased on data in E. D. Crawford's TSCA Incinerator—FY-1994 Bottoms-Up Budget, September 1993.

3.2.1 Costs of Labor and Supervision

The Oak Ridge K-1435 TSCA Incinerator operates on a continuous around-the-clock basis and requires five operators on each shift (five shift positions). This leads to a requirement for 25 total operators to cover all shifts. This is arrived at as follows: An operator works 40 h/week, but, because of holidays, vacations, sick leave, required training, etc., an operator's effective average time is about 34 h/week on a year-round basis. Since a week is 168 h, the total number of operators needed is $5 \times (168/34)$, or about 25 operators. In general, for a plant operating continuously,

$$\text{Total operators} = \frac{\text{number of shift positions} \times 168}{\text{effective hours per week per operator}}.$$

The number of shift positions required to operate a given plant depends on the size and complexity of the plant and an analysis of the duties associated with each shift position. Any special duties resulting from regulatory or DOE requirements should be included in this analysis. At the K-1435 TSCA Incinerator and its associated tank farm/drum storage area, the duties of the operators include management and pretreatment of waste in the K-1425 tank farm, waste incineration, operation of the off-gas cleaning system, management of the scrubber blowdown water, and conducting daily and weekly operational checks. Operators may be control-room operators, field operators (outside the control room), or waste-handling operators. The day-shift operators unload waste shipments, conduct Resource Conservation and Recovery Act (RCRA)/TSCA-required facility inspections, and handle waste transfers. Overtime may be necessary to accommodate excessive work loads, to initiate burning of solid waste, or to take care of absences. Operators also support required maintenance activities during incinerator outages (shutdowns) by performing duties such as (1) handling the disposal of waste items such as used personal protective equipment, brick, ash, sludge, wood, and metal generated during plant operations; (2) providing fresh personal protective equipment such as gloves, Tyvek suits, etc. to maintenance personnel; (3) cleaning out and decontaminating equipment by removing sludge, telerettes, ash, slag, etc.; (4) maintaining

waste storage facilities; and (5) conducting regulatory-required inspections. An overtime rate of 10% was projected for the K-1435 TSCA Incinerator facility for FY-1994 to supplement routine operations, assist in facility upgrades, and cover unforeseen maintenance tasks.

Under supervision and staff, Table 3 shows six shift supervisors (one for each rotating shift plus two relief shift supervisors) and nineteen staff members. The number of staff members was subsequently reduced by one during the budget reconciliation process, giving a final requirement of 18. Key staff positions include Incinerator Operations Manager, Shift Operations Supervisor, Facility Process Engineer, Operations Trainer, Health Physics/Industrial Hygiene Coordinator, Instrumentation Engineer, Technical Operations/Blend Master, and Environmental Engineering Assistant (Trischman 1994).

Costs of labor and supervision account for about 17% of the annual operating budget.

3.2.2 Materials, Supplies, and Laundry Service

Costs of materials, supplies, and laundry service are shown in Table 3 at feed throughputs of 3.5, 5.0, and 4.25 million lb/year. General materials and supplies include disposable protective clothing (suits, boots, headgear and facegear, safety shoes and glasses, earplugs, masks, etc), respirators, cartridges, nosecups, tubes, etc.; flashlights, other lights, batteries, forms, labels, storage boxes, lockout-tagout locks and tags, plastic sheeting, drum liners, strip charts, tape, absorbents, small tools, carbon canisters, placards, etc. Additional supplies of this type specifically required during scheduled outages are also shown. Materials listed as "other materials" are process consumables such as caustic solutions, fuel oil, and drums used to store products.

Table 3 shows the costs of laundry service required to maintain plant-supplied work clothing in proper condition; these costs are independent of plant throughput and are directly related to the number of operators.

Materials, supplies, and laundry service account for about 2% of the annual operating budget.

3.2.3 Utility Costs

Table 4 shows the details of the annual utilities costs of the TSCA Incinerator, based on the FY-1994 Bottoms-Up budget. The consumption of the various utilities was estimated based on past usage and FY-1994 operating plans. Electric power and natural gas are metered and are costed at rates set by the K-25 Power and Utilities Department. Nitrogen is used as a blanketing gas over the feed tanks. Natural gas is used in the primary and secondary auxiliary burners to initiate and maintain combustion. Steam is used for heat, for cleaning out process lines, for atomizing the liquid waste feed, and for general purposes around the plant. Electric power is used for waste liquid and aqueous pumps and other electrically driven equipment; for the off-gas treating system, including the induced draft fan and the ionizing wet scrubber; and for lighting, instruments, and various miscellaneous uses. The annual cost for each utility is obtained by multiplying the estimated rate of consumption in units per year by the unit cost of that utility in dollars per unit.

Utility costs account for about 15% of the annual operating budget.

3.2.4 Unit Costs of Utility Services

The unit costs of utility services at the Oak Ridge K-25 Site, which were used in estimating the budgeted costs for FY-1994, are shown in Table 5. These unit costs are given in terms of dollars per unit of consumption, and costs are shown before adding the 50% overhead charge used in budget preparation for the plant using the utility service. Unit costs for the K-25 Site are set by the K-25 Power and Utilities Department.

3.3 TSCA INCINERATOR COSTS OF SAMPLING AND ANALYSIS

Sampling and analysis are necessary to ensure that operations are in compliance with the conditions specified in the operating permits. Failure to have the necessary compliance analyses could result in shutdown of the incinerator. Sampling and analysis costs account for about 22% of the annual operating budget.

Table 5. Unit costs of utility services at the Oak Ridge K-25 Site^a

Utility	Average cost, \$/unit		Units
	FY 1993	FY 1994	
Nitrogen	8.86	10.24	1000 scf ^b
Natural gas	3.85	3.34	1000 scf
Steam	18.06	16.94	1000 lb
Air	1.38	1.38	1000 scf
Electricity	61.34	64.90	1000 kWh
Sanitary water	2.26	2.59	1000 gal
Sewage disposal	7.26	7.00	1000 gal

^aData supplied by K-25 Plant Services. Unit costs vary from month to month and are shown here as averages for the year-to-date. Costs for FY 1994 are through July 1994.

^bscf = standard cubic feet.

3.3.1 Regulatory Requirements for the K-1435 TSCA Incinerator

The regulatory permits that must be satisfied are Resource Conservation and Recovery Act (RCRA), TSCA, National Pollutant Discharge Elimination Systems (NPDES), National Emissions Standards for Hazardous Air Pollutants (NESHAP), and the State of Tennessee air permit. A very brief description follows.

3.3.1.1 The RCRA Permit

The RCRA permit specifies operating parameter limits and feed limits for various components. Some of the key limits set by the RCRA permit are as follows:

<u>Feed rates:</u>	total feed rate not to exceed 3000 lb/h; organic feed rate to primary waste burner not to exceed 900 lb/h.
<u>Feed heat content:</u>	heating value of primary feed not to be less than 7,000 Btu/lb; secondary feed not to be less than 10,000 Btu/lb.
<u>Ash content of feed:</u>	not to exceed 5 wt%.
<u>Organic chlorine content of feed:</u>	not to exceed 350 lb/h.
<u>Viscosity of feed:</u>	not to exceed 100 cs.
<u>Polychlorinated biphenyl (PCB) content of feed:</u>	must be less than 50 ppm.

3.3.1.2 TSCA Permit

The TSCA permit regulates PCBs in the feed and puts limits on the incinerator operating parameters. Regulations are based on CFR 40 Part 761. A maximum total PCB feed rate of 475 lb/h is specified. This is greater than the maximum permitted by the RCRA permit, and the latter will, therefore, govern.

3.3.1.3 NPDES Permit

The NPDES permit, which is required under the Clean Water Act, specifies that the water discharges from the K-1435 TSCA Incinerator will be permitted to be discharged through the K-25 Central Neutralization Facility (CNF). The principal source of wastewater from the plant is the blowdown water from the quench and off-gas treatment system. The CNF will provide pH adjustment and solids removal as necessary before discharging the water through the NPDES-specified location. The receiving streams are Mitchell Branch and Poplar Creek. Effluent limitations have been placed on the CNF by the Environmental Protection Agency (EPA) and the Tennessee Department of Health. These limitations give rise to the sampling and analysis requirements for the incinerator wastewater.

3.3.1.4 NESHAP Permit

The NESHAP permit is based on the requirements of CFR 40 Part 61, Subpart 4, and sets limits on the quantities of radionuclides that can be fed to the incinerator and discharged from the stack.

3.3.1.5 State of Tennessee Air Permit

The State of Tennessee air permit imposes upper limits on F, Cl, S, Pb, Be, and Hg in the feed, and also imposes stack-discharge limits. It also puts limits on particulates and visible emissions from the stack. The regulations, strictly speaking, apply only to the discharges to the atmosphere, but, to simplify operational control, it was found more practical to set limits on the feed tanks that correspond to the desired limits on stack emissions.

3.3.2 Detailed Cost Experience for the K-1435 TSCA Incinerator

Sampling and analysis services for the K-1435 TSCA Incinerator are provided by the K-25 Analytical Chemistry Department. Analyses are performed at the K-25 laboratory. Routine samples (those taken at regularly scheduled intervals) include wastewater, blend

tank (feed), ash, sludge, NESHAP (stack emissions to atmosphere), feed waste verification (analyses of each shipment of waste received), feed tank (individual feed tanks), and NPDES (liquid discharge). In addition, there are nonroutine samples (not on a regular schedule) including ambient air, combustion gas velocity, K-1425 storage area for incoming waste, and other miscellaneous samples needed to provide guidance for plant operating decisions.

In the preparation of FY-1994 budget estimates for the K-1435 TSCA Incinerator, experience in 1993 and anticipated changes in 1994 were used as guides for the number of samples of each type and the number of person-hours required for the sampling and analysis of each type of sample. These data are summarized in Tables 6 and 7. Table 6 shows the breakdown of costs of sampling, analysis, and testing into its component parts, and Table 7 shows backup data on the number of samples, costs per sample, and total costs for each sampling category. Data for Tables 6 and 7 are from the supporting documentation of the FY-1994 TSCA Incinerator Bottoms-Up Budget.

Wastewater sampling and analyses required by the NPDES permit account for about 25 to 30% of the total sampling and analyses budget. The high cost is primarily a result of the rapid rate of wastewater accumulation (about 60,000 gal/d) and the small size of the two wastewater accumulation tanks (40,000 gal each). At 60,000 gal/d, it takes only two shifts to fill a tank. Each filled tank must be sampled and the analytical results must be available before the contents of the tank can be released to the CNF. Analytical results must be available every 16 h to avoid shutting down the incinerator because of lack of wastewater surge tankage. This accounts for the large number of samples required and for the need to have sampling and analysis services available on an around-the-clock basis.

Waste feed accounts for another major portion of the sampling and analysis budget. Waste feed blends are prepared from several different feed tanks in order to optimize the feed composition to achieve maximum feed rate. Samples must be taken and analyzed before and after the blending operation.

**Table 6. TSCA Incinerator FY-1994 Bottoms-Up Budget:
breakdown of costs of sampling and analysis**

Cost element	Costs, \$/year	
	3.5×10^6 lb/year	5.0×10^6 lb/year
Dedicated persons ^a	\$ 954,624	\$ 954,624
K-1425 (Waste Oil Storage Facility)	36,303	51,861
Wastewater	1,201,891	1,716,987
Blend tank	708,903	1,012,718
Ash	220,214	220,214
Aqueous waste management sludge	220,214	220,214
NESHAP (air emissions) ^b	590,348	590,348
Verification (feed analyses)	303,577	433,682
Feed tank	69,608	99,440
NPDES ^c	36,469	52,099
Ambient air	166,842	166,842
Combustion gas velocity	131,586	131,586
Materials	74,053	74,053
Miscellaneous ^d	205,827	294,038
Total	\$4,920,460	\$6,018,707

^aBasis: five dedicated persons provided by Analytical Services, 1760 full-time equivalent hours per person, cost based on \$72.32/h plus overhead.

^bSampling and analyses required for compliance with NESHAP.

^cTests required for NPDES liquid discharge permit.

^dIncludes special sampling and analyses needed for guidance of plant operations. These are projected on the basis of past data.

Table 7. Detailed backup for costs of sampling and analysis

Stream	Number of samples per year at 3.5×10^6 lb/year	Hours per sample	Hours per year at 3.5×10^6 lb/year	\$ / year ^a		
				3.5×10^6 lb/year	5.0×10^6 lb/year	4.25×10^6 lb/year
Wastewater	^b	^b		11,079	1,201,891	
1,716,987	1,459,439					
Blend tank	164	40	6,535	708,903	1,012,718	860,811
Ash	28	73	2,030	220,214	220,214	220,214
Sludge	28	73	2,030	220,214	220,214	220,214
NESHAP sampling	12	154	1,842	199,820	199,820	199,820
NESHAP analysis	12	300	3,600	390,528	390,528	390,528
Verification	130	21	2,798	303,577	433,682	368,630
Feed tank	49	13	642	69,608	99,440	84,524
NPDES	31	11	336	36,469	52,099	44,284
Ambient air ^c	16	96	1,538	166,842	166,842	166,842
Gas velocity			1,213	131,586	131,586	131,586
Materials				74,053	74,053	74,053
Miscellaneous ^d	127	15	1,897	205,827	294,038	249,933

^aCosts are charged at \$72.32/h plus overhead.

^bNot stated.

^cIncludes trial burn, testing, and reporting.

^dIncludes nonroutine sampling and analysis.

3.4 MONITORING

Table 8 shows the cost breakdown of monitoring services for the TSCA Incinerator. All LLMW treatment facilities have the potential for unintended radiological or chemical contamination of plant equipment and the surrounding environment. At the TSCA Incinerator, the services of several groups are necessary to perform the required monitoring to ensure compliance with regulations designed to protect plant employees and the public. These specialized groups perform their duties for the K-25 Site complex, and their costs are charged to projects or programs based on actual hours worked or on a user percentage distribution. For this reason, no labor or material charges are shown in Table 8. Monitoring costs account for about 4 to 5% of the annual operating budget and are independent of feed rate in the range 3.5 to 5.0 million lb/year.

Health Physics (HP) personnel are responsible for assessing possible worker exposure to radiation and radioactive materials. Health Physics technicians provide monitoring services for tasks such as survey of equipment before removal from radiological zones, survey of buildings for noncontaminated areas or to establish temporary and permanent radiation zones, and assisting operation or maintenance personnel in work that requires additional HP support. Costs for these services are based on actual hours worked. Some workers at the incinerator are monitored for lung exposure by means of bioassay. This service includes the K-25 Site urinalysis program and radiation counter. The K-1435 TSCA Incinerator is charged a percentage (6.22% for FY-1994, based on FY-1993) of the total program cost for the K-25 Site.

Amelioration of physical and chemical stresses in the workplace is the responsibility of the industrial hygienists (IH). Such stresses may occur in confined spaces and other areas where ventilation is restricted and air quality must be closely monitored. Industrial hygiene costs are based on actual hours worked, except for the IH Respirator Program (training, fitting, etc.), which charges the TSCA Incinerator a percentage of total K-25 Site industrial hygiene costs (6.55% in FY-1994, based on FY-1993).

Quality control personnel perform the inspections required by the Occupational Safety and Health Act (OSHA), the RCRA permit, the U.S. Department of Transportation

Table 8. TSCA Incinerator FY-1994 Bottoms Up Budget: breakdown of monitoring costs^a

Cost element	@3.5 × 10 ⁶ lb/year	@5.0 × 10 ⁶ lb/year	@4.25 × 10 ⁶ lb/year
Labor	0	0	0
Materials	0	0	0
Services			
Health Physics			
Routine coverage	\$ 372,263	<i>b</i>	<i>b</i>
Maintenance outage	46,533	<i>b</i>	<i>b</i>
Rad Con implementation	124,088	<i>b</i>	<i>b</i>
Rad worker distribution	213,698	<i>b</i>	<i>b</i>
Industrial Hygiene			
Routine coverage	143,190	<i>b</i>	<i>b</i>
Confined-space work	23,588	<i>b</i>	<i>b</i>
Maintenance outage	71,595	<i>b</i>	<i>b</i>
Respirator wearers distribution (6.22% of K-25 Site total)	4,245	<i>b</i>	<i>b</i>
Nuclear Materials Control & Accountability			
Documentation/traceability support	12,656	<i>b</i>	<i>b</i>
Uranium accounting system	24,635	<i>b</i>	<i>b</i>
Quality Control	104,610	<i>b</i>	<i>b</i>
Total	\$1,141,099	<i>b</i>	<i>b</i>

^aCosts shown include overhead.

^bThese costs are independent of feed rate in the range 3.5–5.0 million lb/year.

(DOT), and the K-25 Site regulations. Inspected equipment includes storage tanks, backflow preventors, material-handling equipment, safety showers, ladders, lifting devices, transport tankers, and mechanical equipment.

Nuclear Materials Control and Accountability (NMC&A) personnel are responsible for the documentation and traceability of all contaminated waste materials containing significant quantities of uranium, as required by DOE Order 5633.3. The distributed costs associated with accounting and computer services are shown under the heading, "Uranium Accounting System," in Table 8.

Other DOE Orders that affect monitoring costs are DOE 5820.2A (Radioactive Waste Management) and DOE 5840.11 (Radiation Protection for Occupational Workers). Overall, it was estimated by Trischman that about 13% of the total costs of monitoring were attributable to DOE Orders (Trischman et al. 1994).

3.5 MAINTENANCE

Table 9 shows the breakdown of maintenance costs for the TSCA Incinerator. The assigned maintenance staff includes one general supervisor, two maintenance supervisors (one instrument and one mechanical supervisor), two planner/estimators, and one clerk. Overtime for these salaried staff members is budgeted at 5%, except for maintenance supervisor overtime, which is budgeted at 15%. Because there is no relief maintenance supervisor, the extra overtime is allotted to take care of unusual maintenance problems that need attention after the day shift ends.

The 23 TSCA Incinerator assigned hourly workers include 8 maintenance mechanics, 9 instrument mechanics, 3 electricians, 2 painters, and 1 laborer. The budget includes an estimate of 15% overtime for maintenance and instrument mechanics and the laborer, 20% overtime for the electricians, and no overtime for the painters. An additional 1.5% overtime charge was estimated at 5.0 million lb/year throughput.

The maintenance mechanics are responsible for the mechanical upkeep at the incinerator and the K-1425 Tank Farm. This includes maintaining or repairing equipment such as pumps, valves, and piping. These mechanics are also responsible for fabricating

Table 9. TSCA Incinerator FY-1994 Bottoms Up Budget: breakdown of maintenance costs^a

Cost element	@ 3.5×10^6 lb/year	@ 5.0×10^6 lb/year	@ 4.25×10^6 lb/year
Labor			
Maintenance staff labor (6)	\$ 384,687	\$ 388,947	\$ 386,817
TSCA-assigned hourly labor (23)	1,523,889	1,550,877	1,537,383
Total labor	\$1,908,576	\$1,939,824	\$1,924,200
Fringe (approximately 31%)	587,843	597,467	592,655
Total labor and fringe	\$2,496,419	\$2,537,291	\$2,516,855
Materials			
Electrical \$	272,790 \$	272,790	\$ 272,790
Mechanical	425,970	\$ 425,970	425,970
Other (respirators, insulation, etc.)	192,000	192,000	192,000
Total material	\$ 890,760	\$ 890,760	\$ 890,760
Services			
Maintenance (building and grounds, preventive, corrective, etc.)	\$ 827,949	\$ 827,949	\$ 827,949
Engineering	17,700	17,700	17,700
Quality Control	33,999	33,999	33,999
Total services	\$ 879,648	\$ 879,648	\$ 879,648

^aBased on data in E. D. Crawford's TSCA Incinerator—FY-1994 Bottoms-Up Budget, September 1993.

and installing new equipment, lifting fixtures, etc. Six mechanics work day shift; the other two work a straight evening shift.

Instrument calibrations and repairs are the responsibility of the nine instrument mechanics. There are four rotating shifts of two people (one works only on the day shift) who perform a total of more than 7,100 calibrations and certifications annually on 640 instruments. Many of these calibrations require two people to perform. These certifications are not only necessary to keep the incinerator functioning in a safe and efficient manner, but are also necessary for compliance under OSHA, the RCRA permit, DOE Orders, etc.

The electricians handle all electrical repairs to noninstrument-type electrical equipment. This includes lighting, electric motors, electrical hook-ups for office equipment, etc. Two electricians work the day shift, and one works only on the evening shift. The electricians also perform the service of electrical lockouts required by Operations and Maintenance personnel before performing work on equipment.

The two painters are needed to maintain the appearance of the plant, prevent rusting of process lines and equipment, and to maintain OSHA compliance. The painters are also used for work necessary to keep the concrete sumps and diked areas well sealed. The laborer's duties include sweeping floors, preparing trash for pickup, and supporting other craft workers to maintain compliance in their areas.

Maintenance costs account for about 17% of the annual operating budget. It was estimated by Trischman that about 11% of the total cost of maintenance is related to DOE Orders, mainly in the area of worker qualifications, training, and supervision (Trischman 1994).

3.6 PROGRAM MANAGEMENT AND SUPPORT

The Program Management and Support Department develops and implements management systems for the control of various division programs including compliance, self-assessment, procedures, training, administrative work management, document control, occurrence reporting, etc. The FY-1994 annual budgeted cost is about 3.8% of

the total operating budget, and breaks down into about 76% labor, 12% materials, and 12% services. About 48% of this cost was directly attributable to the requirements of DOE Orders (Trischman 1994).

3.7 ADMINISTRATIVE

The administrative function provides for overall management, leadership, coordination, and control of the TSCA Incinerator project. It is responsible for interactions with DOE site representatives and site prime-contractor management. It provides program direction and management leadership for operations, maintenance, and facility improvements. Other matters, such as strategic planning, budgeting and financial management, funding, quality assurance, and safety, also are handled under the administrative function.

The administrative function accounts for about 5.4% of the total operating budget. The portion of administrative cost attributable to DOE Orders is about 21% (Trischman 1994).

3.8 ENVIRONMENTAL COMPLIANCE

A number of state and federal regulations must be complied with in order for the TSCA Incinerator to operate, and proof of compliance must be supplied in each case. Costs associated with environmental compliance are shown in Table 10. The Environmental Compliance Department (ECD) consists of three personnel, including one manager. They are assigned to oversee such functions as permit application development and modification, regulatory training for TSCA Incinerator workers, regulatory reports and documents, and many other compliance-related issues. Overtime provisions are budgeted at 10%, excluding the manager. Material costs for ECD consist of permit fees, compliance references, and travel for regulatory training.

The Environmental Management Division (EMD) supports ECD through issuance of required reports (e.g., PCB annual report, NESHAP annual report, etc.). The EMD also assists with development and assessment of environmental programs, contact with

Table 10. TSCA Incinerator FY-1994 Bottoms-Up Budget: breakdown of environmental compliance costs^a

Cost element	@ 3.5×10^6 lb/year	@ 5.0×10^6 lb/year	@ 4.25×10^6 lb/year
Labor			
Total labor (3)	\$248,471	<i>b</i>	<i>b</i>
Fringe (approximately 31%)	76,529	<i>b</i>	<i>b</i>
Total labor and fringe	\$324,999	<i>b</i>	<i>b</i>
Materials			
Permit fees	\$ 50,850	<i>b</i>	<i>b</i>
Compliance materials	12,750	<i>b</i>	<i>b</i>
Travel for training	11,250	<i>b</i>	<i>b</i>
Total materials	\$ 74,850	<i>b</i>	<i>b</i>
Services (EMD)			
Waste generator (4% distribution)	\$ 5,957	<i>b</i>	<i>b</i>
PCB (19% distribution)	50,534	<i>b</i>	<i>b</i>
Low-level waste (4% distribution)	3,332	<i>b</i>	<i>b</i>
Air program support	70,203	<i>b</i>	<i>b</i>
NPDES support	2,006	<i>b</i>	<i>b</i>
PCB	35,102	<i>b</i>	<i>b</i>
RCRA	80,232	<i>b</i>	<i>b</i>
Miscellaneous	12,035	<i>b</i>	<i>b</i>
NEPA	12,035	<i>b</i>	<i>b</i>
Air stack test development	30,087	<i>b</i>	<i>b</i>
Total services	\$301,520	<i>b</i>	<i>b</i>

^aCosts are from the backup data for the FY-1994 budget.

^bThese costs are independent of feed rate in the range 3.5–5.0 million lb/year.

regulatory agencies, interpretation of regulations, and several other functions related to environmental compliance. Most of these services are based on actual hours worked. Some services are distributed on a site-wide percentage basis.

Costs charged to environmental compliance account for about 3% of the annual operating budget.

3.9 TECHNICAL SUPPORT

This function provides the technical and engineering support needed in connection with long-term process and equipment improvements and upgrades, special testing and trial burns, maintenance, capital equipment procurement, feasibility studies, and technical evaluations. Technical support costs account for about 10% of the annual operating budget. About 11% of the technical support budget is directly attributable to DOE Orders (Trischman 1994).

4. OPERATING COST GUIDELINES FOR OTHER TECHNOLOGIES

4.1 BASIS AND SCOPE

General guidelines are presented here for estimating operating costs of other LLMW treatment technologies in a consistent manner as part of the overall benchmarking process. It is assumed that the technologies are to be implemented within a DOE framework similar to that of the TSCA Incinerator. The breakdown of operating cost into its components follows the same pattern as that used for the TSCA Incinerator in Sect. 3. To facilitate comparability of results, it is suggested that this same breakdown be followed uniformly as part of the benchmarking process.

4.2 GUIDELINES FOR PLANT OPERATIONS COSTS

4.2.1 Labor and Supervision Costs for Other Technologies

For a plant using a new technology, it is necessary to make a detailed analysis of operator duties and locations to determine the number of shift positions required. Basic

sources of information are the process flowsheet, the plot plan, the process description, and the process design summary, including equipment descriptions. Familiarity with the process and with the duties of the operators is essential. With this information, a good estimate of the number of operator shift positions can be made by persons experienced in plant operations. Some general rules are: (1) at least one operator is needed inside the control room at all times; (2) the minimum number of operators in an operating plant is two (this is for safety reasons because a lone operator may have an accident and need help); (3) a continuous operation usually requires fewer operators than does a noncontinuous operation; and (4) certain types of specialized equipment may require the frequent attention of an operator.

4.2.1.1 Sensitivity of Labor Costs to Plant Throughput

In large continuous plants such as those in the petroleum-refining and petrochemicals industries, the number of shift positions required is usually not a strong function of plant throughput. In making such a statement, one must be careful to specify whether the number of shift positions is being estimated for a new plant in the design stage or for an existing plant already in operation. For an existing plant, the number of operators usually remains constant as changes in throughput are made within the capacity of the existing equipment. However, when new equipment must be added to expand the capacity of an existing plant, additional operators may be required, depending on the extensiveness of the revisions. For a new plant in the design stage, the number of operators required can be estimated from the requirements of existing plants of the same type, assuming such plants exist. The number of operators required is not likely to exceed that of existing plants of the same type unless there are significant increases in throughput, plot area, number of parallel trains, number of major equipment items such as fired heaters, solids-handling equipment, chemical reactors, rotary-drum filters, large compressors, or in the duties required of the operators. Again, the estimate of the number of shift positions required should be made by persons familiar with operations in plants generally similar to the type of plant under consideration.

4.2.2 Materials and Supplies for Other Technologies

The costs of operating materials and supplies for other technologies will depend to a large extent on the technology. However, the TSCA Incinerator costs for materials and supplies shown in Table 3 can be useful in furnishing some cost guidelines for LLMW thermal-treating technologies in general. The general materials and supplies discussed in Sect. 3.2.2 consist mainly of items common to all such technologies. The annual expense associated with these items appears to be related to two factors: (1) plant throughput and (2) number of operators. The backup cost data for the TSCA Incinerator budget indicate that a 43% increase in throughput (i.e., from 3.5 to 5.0 million lb/year) was accompanied by a 19.4% increase in the cost of general materials and supplies. Also, the costs of items associated with personnel protection account for about 63% of the cost of general materials and supplies and showed an increase of 23% when plant throughput increased by 43%. Additional supplies for outages were 91% attributable to items required for personnel protection (i.e., protective clothing, gloves, respirators, shoes, boots, etc.), because of the nature of the work performed during outages.

The costs listed in Table 3 as "other materials" are for process consumables such as chemicals and product drums and are directly related to plant throughput. These costs are technology dependent and can be determined only by reference to the process design details.

As mentioned in Sect. 3.2.2, the costs of laundry services appear to be directly related to the number of operators; laundry costs do not change when throughput is increased with the same number of operators.

4.2.3 Utility Costs for Other Technologies

The utility requirements of plants using other technologies can be determined accurately only after preparing a complete process design summary including process flowsheets, mass and energy balances, and equipment summaries. In a complex plant, requirements for supplying steam and electricity are frequently optimized by appropriate selection of drivers (steam turbines or electric motors), and the optimum choices are frequently interrelated with the energy balance of the process itself. In the absence of

existing plants using the same technology, there is no way to avoid the preparation of a process design summary if an accurate estimate of utility requirements is desired. Once a complete process design has been prepared, the estimation of utility requirements can be accomplished by standard engineering procedures. For these reasons, guidelines for the estimation of utility requirements are not given here. However, the unit costs of utility services are site-specific. For example, they may depend on the capital and operating costs of steam and electric power plants at the site. Also, the unit cost of purchased electric power can vary widely from one location to another. For comparing technologies, the location should be specified, and the unit costs of utilities at that location should be used and stated. Efficiencies used for pumps, compressors, fans, motors, and combustion equipment should be stated so that utility consumptions can be verified.

4.3 SAMPLING AND ANALYSIS COSTS

The requirements for sampling and analysis for other technologies can be appreciably different from those of the K-1435 TSCA Incinerator. The number of effluent streams, their relative volumes, and the requirements for sampling and analysis are functions of the technology as well as of the type of feed. For this reason, the costs of sampling and analysis experienced at the K-1435 Incinerator cannot be applied to other technologies without a careful analysis of the regulatory requirements applicable to those technologies, the number of streams requiring sampling and analysis, and the extent to which the TSCA experience is relevant.

The same national regulatory requirements apply generally to all technologies, but the manner in which they apply can differ in terms of number of samples and number of analyses because of variations in the flowsheets of the different technologies. Also, the costs of sampling and analysis could be appreciably affected by the choice of techniques for collecting and analyzing samples. For example, stack emissions of metals and radionuclides are currently measured at the K-1435 TSCA Incinerator by collecting sidestream samples continuously on impingers and filters and analyzing the collected

samples at specified intervals. In the case of the K-1435 Incinerator, the use of continuous emission monitoring systems (CEMS) could reduce both the cost of sampling and analysis of the stack emissions and the cost of sampling and analysis of the waste feed tanks, since the latter are used as an indirect control on the stack emissions. However, when making economic comparisons of different process technologies, one should keep in mind that improvements in sampling and analysis techniques used by one technology could, in most cases, be made available to all technologies; and in such cases, it would be unfair to give the benefit of the cost reduction to one technology and not to the others.

4.4 MONITORING COSTS FOR OTHER TECHNOLOGIES

Monitoring costs are largely dictated by OSHA and DOE Orders. These regulations are intended to provide a safe work environment free of radiological, chemical, and physical stresses. When these stresses cannot be avoided, monitoring personnel (e.g., health physicists, industrial hygienists, etc.) are required to ensure that proper safety procedures are followed. This includes establishing radiation or chemical contamination zones and physical hazard areas (e.g., confined spaces), as well as providing proper assistance and instruction, when necessary, to those who must work in these areas.

In estimating annual monitoring costs for other technologies, the effects of differences in process flowsheets, maintenance requirements, and number of operating and maintenance personnel should be taken into account. For example, a waste treatment plant with a greater number of controlled areas (i.e., radiation or chemical contamination zones, confined spaces, etc.) would be expected to incur a greater cost than plants designed with fewer controlled areas. In many cases, monitoring personnel must maintain a presence when work is being performed by others in controlled areas. A larger number of controlled areas, and a greater number of workers entering these areas, will result in increased monitoring costs.

4.5 MAINTENANCE COSTS OF OTHER TECHNOLOGIES

The maintenance costs of the TSCA Incinerator (Sect. 3.5) provide a realistic basis for estimating the maintenance costs of other technologies in a similar setting, that is, in an installation subject to DOE Orders and RCRA, TSCA, and state permitting requirements. Approximately 10.7% of the total maintenance cost of the TSCA Incinerator was estimated to be directly attributable to DOE Orders (Trischman 1994); no estimate has been made of the percentage attributable to regulatory permit requirements. In private industries, such as petroleum refining and chemicals production, annual maintenance costs are frequently estimated as a percentage of equipment cost or, more frequently, of the total erected cost of the plant. In the latter case, the percentage used is usually about 4 to 6%, of which about 40 to 60% is labor and 60 to 40% materials. A standard textbook gives 6% as an average for the process industries (Peters and Timmerhaus 1968). The total fixed investment for the TSCA Incinerator was about \$26 million in 1987. Adjusting for inflation, this corresponds to about \$34 million in 1994 dollars. The maintenance budget for 1994 was about \$4.3 million, or about 12.5% of the total fixed investment annually. On closer examination, however, a significant fraction of the maintenance budget was due to the large number of instrument calibrations needed to satisfy permitting requirements (Jacobs 1994). Without these special requirements and DOE Orders, the maintenance budget would be more in line with the textbook figure of 6%. However, in using such an estimate for a new technology, the impacts of installation and operation within a DOE framework subject to strict environmental regulatory requirements should be adequately accounted for. For this reason, no specific percentage guidelines for maintenance costs are given here; the discussion in Sect. 3.5 will serve as some indication of the factors to be considered.

Other specific considerations for new technologies include possible increased maintenance percentages for equipment operating under unusually demanding process or mechanical conditions. Such factors must be considered on a process-specific basis.

4.6 PROGRAM MANAGEMENT AND SUPPORT COSTS

For the TSCA Incinerator, the costs of program management and support (see Sect. 3.6) were about 3.8% of the total operating budget, and about 48% of these costs were attributable to the requirements of DOE Orders. For other technologies, it would be a reasonable first approximation to assume that these same percentages would apply to projects whose total annual operating costs were of about the same magnitude as those of the TSCA Incinerator. For projects of significantly higher annual operating costs, one might reasonably expect that the costs of program management and support, as a percentage of total operating costs, might decrease. It would also seem reasonable to expect that the percentage attributable to DOE Orders would remain about the same.

4.7 ADMINISTRATIVE COSTS FOR OTHER TECHNOLOGIES

Administrative costs for the TSCA Incinerator are about 5.0 to 5.4% of the total annual operating budget (see Table 1). The same range of percentages might reasonably be expected to apply to other technologies.

4.8 ENVIRONMENTAL COMPLIANCE COSTS

Environmental compliance costs, as used in this report, would not be expected to vary a great deal with different technologies. The main costs are attributable to items such as preparation of reports; support of TSCA Incinerator operations in the development and implementation of environmental permits including RCRA permits, EPA, PCB approval, and state air tests; developing regulatory programs, training, and staying current with changing regulations. These costs are largely independent of the chosen process, because every LLMW treatment process plant would be required to follow essentially the same regulatory rules and regulations. The costs of plant operations (i.e., equipment, materials, personnel, etc.) necessary to operate the process in compliance with regulatory requirements are not included in this cost category because they are already accounted for under Plant Operations (Sect. 4.2). The TSCA Incinerator budgeted cost for environmental compliance, based on actual cost experience, was \$701,000 for FY-1994.

It is suggested that this same amount, adjusted for inflation, would be appropriate for other LLMW treatment technologies.

4.9 TECHNICAL SUPPORT COSTS FOR OTHER TECHNOLOGIES

Technical support costs for other technologies will depend to some extent on the nature of the technology and on the operational experience of the plant after construction and are therefore difficult to predict. For the TSCA Incinerator, costs of technical support (process improvements, equipment problems, piping drawings, etc.) are about 10.2 to 10.5% of the total operating budget. It is suggested that similar percentages might reasonably be expected to apply to other technologies, at least as an initial assumption.

4.10 SUMMARY OF RECOMMENDED GUIDELINES

The recommended guidelines for estimating annual operating costs for benchmarking DOE LLMW thermal treatment systems, as presented in Sects. 4.2–4.9, are summarized in Table 11. The breakdown of operating costs into eight categories is the same as that used in the TSCA Incinerator FY-1994 budget. It is recognized that this way of defining and breaking down operating costs may not be in agreement with procedures used at other DOE installations, or with those used in private industry. It is suggested, however, that the use of a breakdown based on these same cost categories for other technologies will greatly facilitate comparisons on a uniform basis and that this, in turn, will facilitate the mission of the Mixed Waste Integrated Program.

5. CONCLUSIONS

Our conclusions are summarized as follows:

1. General guidelines are presented for the estimation of annual operating costs of process technologies for the thermal treatment of DOE LLMW. These guidelines are intended to be used in the benchmarking (evaluation) of such processes installed in a DOE setting.

**Table 11. Summary of recommended guidelines for estimating annual operating costs
of DOE LLMW thermal treatment technologies^a**

Annual operating cost category	Suggested basis for cost estimation
1. Plant operations	
Labor and supervision (see Table 3)	
Number of shift positions ^b	Base on analysis of process flowsheet, process design summary, and duties of operators
Number of operators	Five times number of shift positions
Number of supervisory and staff positions	24, based on TSCA Incinerator experience
Wage rates and fringe ^c	Base on DOE site location
Materials and supplies (see Table 3)	
General supplies	Base on throughput and number of operators
Additional supplies for outages	Base on number and duration of outages and number of operators
Other materials ^d	Process consumables; base on process requirements and detailed design summary
Laundry service	Base on number of operators
Utilities (see Table 4)	Base on process design analysis and utility unit costs at site. Includes miscellaneous steam and electricity for cleaning, lighting, and maintenance.
2. Sampling and analyses	Base on analysis of flowsheet, number of feed and effluent streams and emissions, and regulatory permit requirements applicable at the site. Also, base on comparable TSCA experience, number of samples, cost of analysis per sample, etc.

Table 11. (continued)

Annual operating cost category	Suggested basis for cost estimation
3. Monitoring (see Table 8)	Base on analysis of process flowsheet and plot plan (plant layout). Assume regulatory requirements and DOE Orders are similar at all DOE sites, except for State requirements, which are site-specific
4. Maintenance (see Table 9)	Base on analysis of process flowsheets, process design summary, and types of equipment used, and take into account DOE Orders and other regulatory requirements
5. Program management and support	3.8% of total budgeted annual operating cost, based on TSCA Incinerator experience
6. Administrative	5.0–5.4% of total budgeted annual operating cost, based on TSCA Incinerator experience
7. Environmental compliance (see Table 10)	About \$700,000/year (about 2.8% of annual budget) in FY-1994, based on TSCA Incinerator experience; apply escalation as necessary
8. Technical support	10.2–10.5% of total budgeted annual operating cost, based on TSCA Incinerator experience

^aBased on a project and supporting staff organization at a DOE site.

^bThis is the number of operators on duty on any one shift.

^cFringe is also known as labor burden.

^dProcess consumables proportional to throughput such as catalysts, chemicals, containers used for products, etc.

2. When comparing the operating costs of different technologies, it should be kept in mind that cost is only one element of the evaluation process. Technologies that achieve different levels of emissions control or that do not apply to the same range of feedstock types or compositions cannot be compared on the basis of cost alone.
3. In addition, the economic comparison of competing processes has little validity if the process designs have not been carried to the same degree of detail. Detailed flowsheets, mass and energy balances, equipment lists, and analysis of potential operating difficulties are necessary before reliable capital and operating cost estimates can be made.
4. A previous paper (Trischman 1994) concluded that the operating cost addition directly attributable to DOE Orders was about 13% of the annual operating budget. The same paper also concluded that the additional cost of compliance with DOE Orders is reasonable for the level of safety, quality, and uniformity that they provide. We agree with those conclusions. We conclude also that the costs of compliance with DOE Orders must be uniformly taken into account when estimating the operating costs of new LLMW treatment technologies installed at DOE facilities.
5. The study presented here serves as a benchmark for operating costs of rotary-kiln incineration of DOE LLMW in a liquids feed wet off-gas system mode. The benchmarking process is based on the "cradle-to-grave" concept; the overall costs of disposing of wastes should be considered, including wastes generated within the process (Hoffmann et al. 1994). The TSCA Incinerator has not run on solids or sludge in a continuous operating mode, so actual operating costs for solids and sludge treatment operations are unknown. If secondary treatment is required to satisfy product acceptability, the costs of such secondary treatment (or of

management of secondary wastes) should be part of the benchmarking process (Dalton 1993). New technology has the potential for reducing secondary treatment requirements for robust waste feedstocks (mixtures of solids, liquids, and sludges). This could result in significant cost savings relative to incineration, but full-scale operating data are thus far unavailable.

6. REFERENCES

- Dalton, J. D., Harris, T. L., and DeWitt, L. M., August 1993. *Technical Area Status Report for Waste Destruction and Stabilization*, DOE/MWIP-4, Science Applications International Corporation, Idaho Falls, Idaho.
- Hoffmann, D. P., Gibson, L. V., Hermes, W. H., Bastian, R. E., and Davis, W. T., Jan. 1994. *Guidelines for Benchmarking Thermal Treatment Systems for Low-Level Mixed Waste*, DOE/MWIP-19, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, Tenn.
- Jacobs, April 15, 1994. *Toxic Substance Control Act (TSCA) Incinerator FY94 Operating Budget Review*, Jacobs Engineering Group, Inc.
- Peters, M. J., and Timmerhaus, K. D., 1968. *Plant Design and Economics for Chemical Engineers*, 2d ed., McGraw-Hill, New York.
- Trischman, S., Adams, V., Sadhukhan, P., and Perez, F., 1994. "Impact of Department of Energy Orders on Mixed Waste Treatment Operations: A Case Study of the Toxic Substances Control Act Incinerator," pp. 1-7 in *Proc. 1994 International Incineration Conference, Houston, Texas, May 9-13, 1994*, University of California, Department of Environmental Health and Safety, Irvine, Calif.

INTERNAL DISTRIBUTION

1. T. J. Abraham
2. W. Altman
3. W. Anderson
4. P. Backus
5. M. Baer
6. M. Baker
7. H. Beeson
8. J. M. Begovich
9. J. Berry
10. G. Bloom
11. G. Boris
12. W. Bostick
13. C. Brown
14. C. Buttram
15. R. Canon
16. J. Chiang
17. T. Conley
18. A. G. Croff
19. S. Crosley
20. C. Daugherty
21. J. Dunn
22. M. Elmore
23. J. J. Ferrada
24. R. Fellows
25. C. W. Forsberg
26. C. Frye
27. R. K. Genung
28. L. V. Gibson
29. T. M. Gilliam
30. R. Glass
31. E. Harrington
32. H. Haselton
33. H. Hayden
- 34-38. W. H. Hermes
39. J. R. Hightower
40. D. P. Hoffmann
41. D. Hutchins
42. A. S. Icenhour
43. G. Kamp
44. J. Kennerly
45. R. R. Kimmitt
46. J. A. Klein
47. D. Kucsmas
48. H. Lee
49. D. Lennon
- 50-54. S. L. Loghry
55. S. B. Ludwig
56. A. P. Malinauskas
57. A. Mattus
58. C. Mattus
59. E. McDaniel
60. L. E. McNeese
61. D. Milewski
62. M. I. Morris
63. D. Moser
64. J. W. Nehls
65. C. Newman
66. I. W. Osborne-Lee
67. B. D. Patton
68. F. Perez
69. J. Perona
70. R. B. Pope
71. R. R. Rawl
72. W. J. Reich
73. A. Richmond
74. T. Rogers
- 75-79. R. Salmon
80. R. Sams
81. J. T. Shor
82. W. K. Simon
83. S. P. N. Singh
84. L. Stinton
85. S. N. Storch
86. H. P. Wayland
87. Central Research Library
88. Document Reference Center
89. ORNL Patent Section
- 90-91. ORNL Laboratory Records
92. ORNL Laboratory Records, RC
93. Y-12 Document Reference Section

EXTERNAL DISTRIBUTION

94. V. Adams, U.S. Department of Energy, Oak Ridge Operations, P. O. Box 2003, Oak Ridge, TN 37831-7345
95. N. Askew, Westinghouse Savannah River Co., P.O. Box 616, Aiken, SC 29802
96. C. Baldwin, EG&G Rocky Flats, P.O. Box 464, Golden, CO 80402-0464
97. M. Ballestri, BDM Federal, 20251 Century Blvd., 4th Floor, Germantown, MD 20874
98. L. M. Barton, Jr., Vortec Corporation, 3370 Ridge Pike, Collegeville, PA 19426-3158
99. J. Bassi, 418/TREV, EM-351, U. S. Department of Energy, Washington, DC 20585-0002
100. R. Bastian, Focus Environmental, 9050 Executive Park Dr., Suite A-202, Knoxville, TN 37923
101. S. Bates, EG&G Idaho Inc., P.O. Box 1625, MS-3930, Idaho Falls, ID 83415-3930
102. T. Bergsman, Battelle Pacific Northwest Laboratory, MS P7-41, P. O. Box 999, Richland, WA 99352
103. P. Biswas, Environmental Engineering, University of Cincinnati, Cincinnati, OH 45221-0071
104. W. J. Bjorklund, Battelle Pacific Northwest Laboratory, MS P7-79, P.O. Box 999, Richland, WA 99352
105. L. Borduin, Los Alamos National Laboratory, MS K-557, P.O. Box 1663, Los Alamos, NM 87545
106. M. Brooks, Waste Policy Institute, 555 Quince Orchard Rd., Suite 600, Gaithersburg, MD 20879
107. D. Brooman, Belfort Engineering Services, 2021 Century Blvd., Bellemeade Bldg., 4th Floor, Germantown, MD 20874
108. G. Bryan, Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352

109. H. Burns, Westinghouse Savannah River Co., Bldg. 704-61S, P.O. Box 616, Aiken, SC 29808
110. P. Castel, U.S. DOE/HQ, WINCO, 20201 Century Blvd., Rm. 408, Germantown, MD 20874
111. D. Chaiko, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439
112. W. Clark, Energy and Environmental Research Corp., 18 Mason, Irvine, CA 92718
113. C. Collier, BDM Federal, 20251 Century Blvd., 4th Floor, Germantown, MD 20874
114. C. Cooley, EM-50, 449/TREV, U. S. Department of Energy, Washington, DC 20585-0002
115. J. Cooper, Chester Environmental, 12242 S. W. Garden Place, Tigard, OR 97223
116. T. Cooper, Westinghouse Hanford Corp., MS N3-12, 2355 Stevens Dr., Richland, WA 99352
117. A. Corstillo, FERMCO, 25 Merchant Street, Springdale, OH 45246
118. S. Couture, Lawrence Livermore National Laboratory, L-591, P.O. Box 808, Livermore, CA 94551
119. G. Coyle, EM-532, 413/TREV, U.S. Department of Energy, Washington, DC 20585-0002
120. J. Cudahy, Focus Environmental, 9050 Executive Park Drive, Suite A-202, Knoxville, TN 37923
121. J. Cunnane, Argonne National Laboratory, 9700 S. Cass Ave., Bldg. 205, Argonne, IL 60439
122. J. Dancz, SAIC, 555 Quince Orchard Rd., Suite 500, Gaithersburg, MD 20878-4137
123. W. Davis, University of Tennessee, College of Engineering (Civil & Env. Eng.), Knoxville, TN 37996-2010
124. C. Dempsey, Risk Reduction Engineering Laboratory, US EPA, Cincinnati, OH 45224
125. S. Domotor, EM-351, U.S. Department of Energy, Trevion II, Washington, DC 20585-0002

126. M. Durham, ADA Technologies Inc., 304 Inverness Way South, Suite 110, Englewood, CO 80112
127. A. Eicher, Focus Environmental, 9050 Executive Park Dr., Suite A-202, Knoxville, TN 37923
128. P. Erickson, EPA-RREL, MS 489, 26 W. Martin Luther King Dr., Cincinnati, OH 45268
129. R. Eschenbach, Retech Inc., P.O. Box 997, Ukiah, CA 95482-0997
130. J. Fannon, EM-50, U.S. Department of Energy, 2021 Century Blvd., Germantown, MD 20874
131. C. Frank, EM-50, 5B-104/FORS, U.S. Department of Energy, Washington, DC 20585
132. E. Franz, Brookhaven National Laboratory, 34 North Railroad St., Bldg. 830, Upton, NY 11973
133. G. Frazier, University of Tennessee, College of Engineering, Knoxville, TN 37996-2010
134. Dr. N. French, Sandia National Laboratory-Livermore, 7011 East Ave., Livermore, CA 94550
135. M. Fuhrmann, Brookhaven National Laboratory, 34 North Railroad St., Bldg. 703, Upton, NY 11973
136. A. Gatuchette, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, 26 W. Martin Luther King Blvd., Cincinnati, OH 45268
137. R. Gay, Rockwell International, 6633 Canoga Ave., MS-T006, Canoga Park, CA 91303
138. R. Gehrke, EG&G Idaho Inc., 2151 N. Blvd., MS-7111, Idaho Falls, ID 83415
139. R. Geimer, SAIC , 545 Shoup Avenue, Suite 200, Idaho Falls, ID 83402-3577
140. J. Gill, James H. Gill & Associates, 12015 Manchester, St. Louis, MO 63131
141. R. Gillins, SAIC, 545 Shoup Ave., Suite 200, Idaho Falls, ID 83402-3577
142. K. Hain, EM-55, U.S. Department of Energy, 1000 Independence Ave. SW., Washington, DC 20585

143. P. Hart, EM-542, U. S. Department of Energy, Trevion II, Washington, DC 20585-0002
144. Dr. J. Helt, Argonne National Laboratory, 9700 S. Cass Avenue, Bldg. 205, Argonne, IL 60439
145. D. Helton, Westinghouse Savannah River Co., Trevion I, Room 453, Germantown, MD 20874
146. C. Henke, Focus Environmental, 9050 Executive Park Dr., Suite A-202, Knoxville, TN 37923
147. J. Hillary, EG&G Idaho, Inc., P. O. Box 1625, Idaho Falls, ID 83415
148. G. Hinshaw, Midwest Research Institute, 425 Volker Blvd., Kansas City, MO 64110
149. D. Hjeresen, Los Alamos National Laboratory, AET, MS-P641, Los Alamos, NM 87545
150. J. Hnat, Vortec Corporation, 3770 Ridge Pike, Collegeville, PA 19426
151. T. Ho, Lamar University, P.O. Box 10053, Beaumont, TX 77710
152. J. Hunter, Westinghouse Hanford Co., P.O. Box 1970, MS L531, Bldg. 3766, Rm. 14, Richland, WA 99352
153. J. Jacquin, SAIC, 555 Quince Orchard Rd., Suite 500, Gaithersburg, MD 20878
154. P. Jones, BDM Federal, 555 Quince Orchard Rd., Suite 400, Gaithersburg, MD 20878-1437
155. P. Kalb, Brookhaven National Laboratory, 34 North Railroad St., Bldg. 830, Upton, NY 11973
156. T. Kan, Lawrence Livermore National Laboratory, P.O. Box 808, MS-1467, Livermore, CA 94550
157. R. Koenig, Merlin Co./Boulder, Inc., 395 Ridgeview Lane, Boulder, CO 80302
158. K. Kostelnik, EG&G Idaho Inc., P.O. Box 1625, MS-3930, Idaho Falls, ID 83415-3930
159. D. Kried, Battelle Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352

160. O. Krikorian, Lawrence Livermore National Laboratory, P.O. Box 808, L-369, Livermore, CA 94550
161. O. Kruger, Westinghouse Hanford Company, 2355 Stevens Drive, MS H5-33, Richland, WA 99352
162. C. Lee, EPA Risk Reduction Engineering Laboratory, 26 W. Martin Luther King Blvd., Cincinnati, OH 45268
163. J. Lightly, University of Utah, Salt Lake City, UT 84112
164. J. Lippold, BDM Federal, 555 Quince Orchard Road, Suite 400, Gaithersburg, MD 20878
165. J. Mayberry, SAIC, 545 Shoup Ave., Suite 200, Idaho Falls, ID 83402-3577
166. J. McCray, WINCO, P. O. Box 4000, MS-5218, Idaho Falls, ID 83415-4000
167. W. McCulla, Los Alamos National Laboratory, SM 30 Warehouse, Bikini Rd., S J-563, Los Alamos, NM 87545
168. J. McFee, IT Corporation, 5301 Central Ave., Suite 700, NE, Albuquerque, NM 87108
169. C. McVay, Westinghouse, Savannah River Site, Bldg. 704-45S, P. O. Box 616, Aiken, SC 29802
170. Dr. X. Meng, Center for Environmental Engineering, Stevens Institute of Technology, Hoboken, NJ 07030
171. T. Miller, University of Tennessee, 73 Perkins Hall, College of Engineering, Knoxville, TN 37996-2010
172. T. Moberg, Westinghouse Hanford Co., P.O. Box 1970, MS-425, Richland, WA 99352-1970
173. J. O. Moore, U.S. Department of Energy, P.O. Box 2001, Oak Ridge, TN 37830-8620
174. C. Nagel, Molten Metal Technology, 51 Sawyer Road, Waltham, MA 02154
175. R. Nakaoka, Los Alamos National Laboratory, P.O. Box 1663, MS-6517, Los Alamos, NM 87545
176. M. Nawar, Office of Radiation Programs, 401 N St., S.W., Washington, D.C. 20460

177. J. Newburn, Thermatrix Inc., 308 N. Peters Rd., Suite 225, Knoxville, TN 37922
178. G. Ordaz, U.S. Department of Energy, EM-541, Trevion II, Washington, DC 20585-0002
179. T. Overcamp, Clemson University, 342 Computer Ct., Environmental Systems Eng., Anderson, SC 29625
180. C. Owens, EG&G Idaho, P. O. Box 1625, Idaho Falls, ID 83415-3960
181. R. Peters, Battelle Pacific Northwest Laboratory, P.O. Box 999, MS P7-41, Richland, WA 99352
182. H. Pham, Air Products and Chemicals Inc., 7201 Hamilton Blvd., Allentown, PA 18195-1501
183. B. Place, Westinghouse Hanford Co., P.O. Box 1970, MS-H5-33, Richland, WA 99352
184. R. Price, Duratek, 8955 Guilford Rd., Suite 200, Columbia, MD 21046
185. G. Reed, University of Tennessee, College of Engineering, Knoxville, TN 37996-2010
186. W. Ross, Battelle Pacific Northwest Laboratory, P.O. Box 999, MS K7-90, Richland, WA 99352
187. P. Sadhukhan, Jacobs Engineering Group, Inc., P. O. Box 53495, Houston, TX 77052
188. A. F. Sarofim, Department of Chemical Engineering, MIT, 66-572, Cambridge, MA 02139-4307
189. R. Schumacker, Westinghouse Savannah River Co., SRTC, P.O. Box 616, Bldg. 773-42A, Aiken, SC 29808
190. B. Schutte, Trevion II, EM-54, U. S. Department of Energy, Washington, DC 20585-0002
191. B. Schwinkendorf, BDM Federal, 1801 Randolph Rd., SE, Albuquerque, NM 87106
192. W. Searles, Associated Technical Consultants, 2375 Dorr St., Suite I, Toledo, OH 43607-3406
193. R. Seeker, EER Corp., 18 Mason Drive, Irvine, CA 92718

194. G. Sevigny, Battelle Pacific Northwest Laboratory, P.O. Box 999, MSIN P7-43, Richland, WA 99352
195. M. Shupe, EM-531, 415/TREV, U.S. Department of Energy, Washington, DC 20585-0002
196. D. Singh, Argonne National Laboratory, 9700 S. Cass Ave., Bldg. 212, Rm. G-233, Argonne, IL 60439
197. S. Slate, Pacific Northwest Laboratory, P.O. Box 999, KI-25, Richland, WA 99352
198. E. F. Snow, Plasma Energy Applied Technology Inc., 4914 Moores Mill Rd., Huntsville, AL 35811
199. G. Sprenger, EG&G Rocky Flats, P.O. Box 464, Bldg. 750, Golden, CO 80402-0464
200. M. Springer, Plasma Energy Applied Technology Inc., 4914 Moores Mill Rd., Huntsville, AL 35811
201. S. Stein, Battelle Seattle Research Center, 4000 NE 41ST St., Seattle, WA 98105-5428
202. M. Stevenson, SAIC, 545 Shoup Ave., Idaho Falls, ID 83402-3575
203. P. Sydenstricker, BDM Federal, 555 Quince Orchard Rd., Suite 400, Gaithersburg, MD 20878
204. T. Timmerman, Mason & Hanger, P.O. Box 30020, Bldg. 9-059, Amarillo, TX 79177
205. T. Uhlmeyer, MD-Ferguson Co., 7295 Highway 94 South, St. Charles, MO 63304
206. R. VanKonynenburg, Lawrence Livermore National Laboratory, P.O. Box 808, L369, Livermore, CA 94550
207. J. Vavruska, Equinox Ltd., 872 Don Cubero Ave., Santa Fe, NM 87501
208. C. Ward, Westinghouse Savannah River, P.O. Box 616, Bldg. 773-A, D-1134, Aiken, SC 29808
209. S. Warren, EM-442, 149/TREV, U. S. Department of Energy, Washington, DC 20585-0002

210. L. Waterland, Accurex Environmental Corp., P.O. Box 7044, Mountain View, CA 94039
211. J. Whittle, Electropyrolysis Inc., 996 Old Eagle School Rd., Wayne, PA 19087
212. J. Witzeman, Westinghouse Company, P.O. Box 398704, Cincinnati, OH 45239-8704
213. S. Wolfe, EM-532, 413/TREV, U.S. Department of Energy, Washington, DC 20585-0002
214. W. Wolfe, SAIC, 545 Shoup Ave., Idaho Falls, ID 83402-3575
215. R. Womack, Retech Inc., P.O. Box 997, Ukiah, CA 95482-0997
216. M. Zenkovich, EM-323, Trevion II, U.S. Department of Energy, Washington, DC 20585-0002
217. Office of Assistant Manager, Energy Research and Development, Department of Energy, Oak Ridge Operations Office, P.O. Box 2008, Oak Ridge, TN 37831-6269
218. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831