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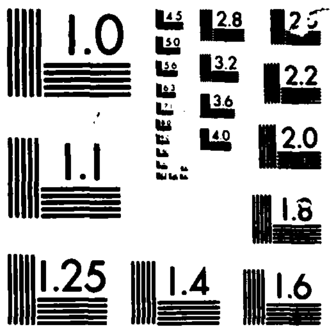

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By R.M. Roberts

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APPLICATION GUIDE FOR HEAT RECOVERY INCINERATORS

ABSTRACT This document is intended to assist activity commanders in deciding if an HRI system is a cost-effective means for managing solid wastes and reducing the draw on conventional energy sources. Guidelines are provided on how such a system should be configured in order to give the best results for a particular application.

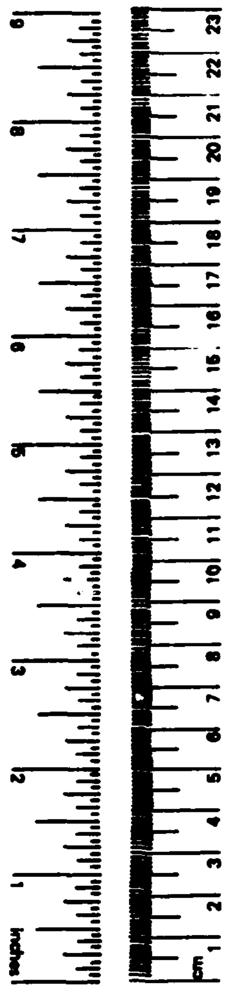
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

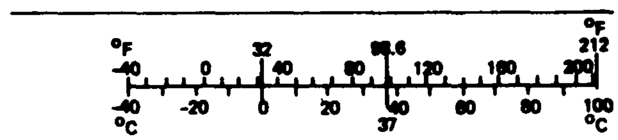
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Naval Facilities Engineering Command policy regarding HRI construction at Navy activities is to seek alternative waste management opportunities such as the use of nearby resource recovery facilities that have been financed and erected by private operators or civic entities.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Waste to energy, solid waste management, heat recovery incinerator (HRI), application guide

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

This document is intended to assist activity commanders in deciding if an ~~HRI~~ system is a cost-effective means for managing solid wastes and reducing the draw on conventional energy sources. Guidelines are provided on how such a system should be configured in order to give the best results for a particular application.

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CONTENTS

BACKGROUND

The President's Executive Order 12003 of July 1977 directed that all Government activities achieve a 20% reduction in energy consumption per gross square foot by FY 1985. Because the accountability for energy is based on conventional (fossil) fuel consumption and purchased electricity, steam, and hot water, energy derived from alternative sources operated by an activity constitutes an energy benefit. Thus, the use of alternative energy sources, such as solar, geothermal, wind, waste oil, or solid waste, brings energy credits even though actual conservation of energy itself may not be realized. These processes must, however, be cost effective when compared to the processes they replace.

The firing of solid waste in a Heat Recovery Incinerator (HRI) is an attractive approach to take since the fuel is essentially cost free and use of the HRI should simplify solid waste management. This approach can be misleading, however, if the potential user does not fully evaluate the many factors that determine whether such a system would be appropriate for a given activity.

This document is intended to assist activity commanders in deciding if an HRI system is a cost-effective means for managing solid wastes and reducing the draw on conventional energy sources. The document further provides guidelines on how such a system should be configured in order to give the best results for a particular application.

HRI APPLICATION DECISION

Certain factors must be considered in the decision to select an HRI system regardless of whether the rationale is the realization of an energy offset or a more cost-effective means of solid waste management, or both. These decision factors have been incorporated into a decision diagram, Figure 1, that includes the key elements of the decision logic. The reader starts at the upper left corner in Box 1 and ends in one of the two final decision balloons. When the reader completes the diagram and reaches the balloons, he will have decided that nothing needs be done or that of an HRI construction project should be begun. As the planner works towards these conclusions, the cost benefits of the HRI versus present practice and possible outside solid waste management (SWM) opportunities are compared at various points in the iteration. At whatever level the diagram is being tested, if balloon 17 ("Maintain Status Quo") is reached, the process can be aborted without further immediate research. Even then, however, Box 16 ("Any Emerging Outside Opportunities?") should be periodically tested to update and possibly reactivate the decision process. Conversely, if balloon 35 is reached, the Navy activity will already be preparing to change over its SWM practices to center on an HRI system or an outside SWM plan as the principal disposal mechanism.

In designing the decision diagram, it has been assumed that the user has an incentive for using it. That is, some particular aspect of the user's SWM plan is not as cost-effective as it could be, or will become more costly in the near future, or would obviously benefit from the introduction of some new strategy for resource recovery. The assumption has also been made that the user does not have all the facts he could have regarding his in-place SWM program. If that assumption is incorrect, then the well-informed user will be able to exercise the decision diagram in a comparatively short time.

Increasing refinement of data quality is called for at each of the iterations so long as the process is worth pursuing. To assist in the development of those data inputs requiring enhancement at particularly Levels I and II of the diagram, four worksheets have been developed; they are summarized in Table 1.

ELEMENTS OF THE DECISION DIAGRAM

Presented below are explanations of the controls and the actions taken in each of the elements of the decision diagram (Figure 1). These discussions are arranged with the elements in serial, not logical order. This is to facilitate finding the information as one proceeds through the decision diagram. As a consequence of this arrangement, there will often be breaks in the continuity of the decision process if one simply reads from Element No. 1 to No. 35.

(1) Are Outside SWM Operations Accessible? The recommended first step to upgrading one's SWM operations economically is to give the problem to someone else. NAVFAC's policy is that HRI plants should not be built by the Navy at all. Therefore, support the surrounding communities in their endeavors to upgrade and reduce costs of solid waste management through resource recovery projects. Offer to join in such ventures by pooling the Navy solid wastes with those of the civilian sector; consider the purchase of steam, if that is the resource to be recovered. Economics, of course, must be favorable with respect to what is already being done at the Navy activity.

In a sampling of 28 Navy activities within CONUS, NCEL (Ref 1) determined that half the activities relied on contractors to handle all phases of their SWM operations. Using a contractor does not necessarily mean finding an HRI operation on the outside. Municipalities and commercial entrepreneurs have also operated other noncombustive types of resource recovery systems, and some are still being tried although with marginal results typically. As disposal costs increase, however, such alternative schemes could take hold. They are briefly discussed later in this report.

The reader should find out what SWM practices are being used in the areas surrounding his activity. There may be a number of possible civilian SWM operations functioning nearby that might be economically accessed. Examples of such opportunities are:

a. Bring in private haulers and retire your own collection/disposal program.

b. Haul to closer landfills or transfer stations owned by others.

c. Haul the solid wastes to a local resource recovery facility (possibly a municipal waste-fired steam generator), etc.

Information collected should include site locations, tipping fees, and owner attitude towards handling Navy solid waste. If nothing else is found worth further investigation, skip to box 4.

(2) Are Cost Savings Available? If an outside SWM operation that the Navy can access appears to be economically attractive, then realistic cost comparisons should be worked up. While the outside entrepreneur will readily furnish detailed pricing information, equivalent data for the existing SWM operations of the Naval activity may not have been accurately developed. To determine if your disposal costs are reasonable, Table 2 lists ranges of typical disposal costs for 28 Navy activities throughout CONUS. These costs include both Public Works Department (PWD) and contract costs and thus represent competitive rates. Waste collection costs are not included, since these apply to whatever disposal process is involved. If from these calculations it is apparent that money will be saved by contracting out certain or all facility SWM operations, then move on to box 3, if not, to box 4.

(3) Would A Joint Venture Be Approvable? Any outside SWM contract will involve various terms and conditions. These may range from routine matters that are of minor local significance to quite problematic if not preclusive requirements. Therefore, it will be important to acquire counsel early to assess legality and to determine the probable position of the chain of command towards endorsing the deal. Proceed onto box 5.

(4) Outside Future SWM Planned Operations Accessible? Failing to locate an ongoing outside SWM program that a Navy activity can gainfully access, inquiries should still be made to determine if suitable SWM projects may be planned. In fact, information on future plans can be acquired while the search is made to find active SWM operations on the outside.

An important benefit of expressing interest in planned SWM projects is that the design can sometimes be modified to accommodate the inclusion of Navy requirements. It will therefore be worthwhile to establish a friendly rapport with the SWM offices of the adjacent communities, county, and association of local governments. The office of Solid Waste Management Programs of the U.S. Environmental Protection Agency and the State or territorial counterpart can be helpful as can the various professional and trade societies dedicated to resource recovery and energy conservation.

If a project in the planning stage is found that appears likely to offer the Navy a cost beneficial SWM approach, then proceed to box 8. If no such project is found or if the potential opportunities are too vaguely defined or uncertain, then proceed to box 5.

(5) Present SWM Costs at Activity Acceptable? If an outside, cost-saving SWM operation is not currently accessible, internal alternatives should be considered to determine whether the costs of existing SWM procedures are really acceptable or not. Going to an outside operation usually will entail little if any capital investment and is readily justified by the cost saving available, provided offsetting sacrifices (e.g., in security, aesthetics, quality of service) are not involved. Developing alternative, internal SWM procedures (e.g., baling, compacting, etc.) on the other hand, typically will entail significant capital costs that can only be justified by a short pay back and long term savings. These benefits do not usually materialize unless the existing practice is unduly expensive because of some particular burden (e.g., distance to landfill, etc.).

Worksheet 1 (WS1), which is found in Appendix A together with the other worksheets used here, should be entered at this point to compute disposal costs. If after comparing the disposal costs generated in WS1 with typical disposal costs (from Table 2), the SWM costs for your activity are unreasonably high, proceed to box 6. If the costs are within normal range for your area, proceed to box 9 but remember to periodically update yourself on outside SWM planning (box 4).

(6) Solid Waste Flow Sufficient to Consider Alternatives? If the waste flow of the activity is below a critical level, an HRI will not be cost effective. The minimum waste rate has been estimated at 10 ton per day (TPD) for mass-fired, facility-steam HRIs (Ref 2). A mass-fired, turboelectric HRI plant rated at less than 250 TPD would probably not be economically viable (Ref 3). For the first level of iteration, assume TPD is equal to tons per year (TPY) divided by 260 operating days per year. For the first level of iteration, Table 3 lists all (72 total) of the activities within the Naval Establishment generating solid wastes in amounts estimated by NCEL to exceed 15 tpd. These estimates were generated by linear programming technique utilizing waste rates previously estimated for 28 activities (Table 4). If your activity is listed, proceed to box 7; if not, proceed to box 11.

(7) Activity Energy Draw Large and Continuous Enough? Given an adequate waste flow rate, you must now consider whether the waste energy available can be profitably applied to supplement the existing energy supply system. For Level I estimating, assume that about 200 lb/hr of saturated steam is generated for each tpd of refuse generated. With the rough estimate of refuse generated at your activity (box 6), you can determine approximately what the conversion in steam flow will be over the pressure range of 100 to 500 psi. If the result is less than 20% of the total steam flow for a large saturated steam loop at the activity, then it can probably be accepted without serious impact on the existing steam generators. If a higher fractional input would be involved and split flow to two or more loops is not practical, consult with the PWD Utilities Division Manager as to the feasibility of accommodating larger steam flows.

If a compatible energy-consuming system can be made available, then move on to box 12. If the energy produced by the HRI simply cannot be used in a cost effective manner, then move on to box 15.

(8) Cost Beneficial and Compatible with Navy's Needs? Any future SWM plan must be compatible with the projected SW disposal needs of the Navy activity and be cost effective over the present SWM program.

If a future SWM program meets the Navy's requirements and will be more cost-beneficial than the projected present plan, go back to box 3. If the project in-planning does not satisfy the two requirements, proceed to box 5.

(9) Disposal Costs to Increase Disproportionately? One must consider whether a future disproportional rise in disposal costs would reach an unacceptable level and require the re-evaluation of an alternative SWM program.

The disposal costs most likely to rise disproportionately to other costs would include fuel, disposal site fees, and hauling costs if the landfill in use is closed. Disposal costs are, of course, also highly dependent on the life expectancy of landfill and the relocation options. If a future nonproportional rise in disposal costs is anticipated and would prove unacceptable, then advance to box 6 for future study of alternative SWM possibilities. If the foreseen rise is acceptable, then proceed to box 10 to consider a possible increase in energy costs.

(10) Energy Costs to Increase Disproportionately? Again, the rise in future costs must be evaluated in relation to other costs. In recent years, energy costs have risen at a signficantly higher rate than other costs. It has been stated (Ref 4) that the cost of steam is increasing at a rate of 6.3 percent per year. This is in contrast to a current (1984) general inflation rate of 4.0 percent, or about a 60 percent faster rate of increase. If the energy prices are anticipated to rise faster than other SWM costs, proceed to box 6 for further evaluation of alternative SWM plans. If the increase in the cost of energy is proportional to other SWM costs increases and an on-site alternative SWM plan is not viable, proceed to box 15.

(11) SW Available from Other Government Activities? The minimum SW flow rate requirements for economical HRI operation are 10 tpd for mass-fired steam HRIs and 60 tpd for HRIs firing RDF prepared on-site (Ref 5). To achieve the minimum daily SW flow requirements an investigation into obtaining SW from other government activities may prove worthwhile and economically beneficial to all parties involved. If a sufficient solid waste flow rate can be obtained from additional sources, proceed to box 7, if not, proceed to box 15.

(12) Is the HRI Concept Economically Viable? To proceed further in this study, one must determine if the HRI concept is economically sound; do the benefits outweigh the costs?

Benefits of the HRI come from the savings in disposal costs and the energy credit generated. The operating costs of the HRI and initial capital cost of the plant comprise the total costs for level I analysis.

Complete Worksheet 3 to determine the costs and benefits of installing an HRI and whether the project is economically viable.

If the construction and operation of an HRI is an economically viable alternative, proceed to box 13. If the benefit to cost ratio is less than one, go to box 15.

(13) Is an HRI More Cost Effective Than an Outside Venture? The HRI was shown to be an economically viable concept but how does it stand up to other alternatives? Compare the costs and benefits of an outside SWM program (if one was found acceptable in box 3) to the corresponding costs and benefits of the HRI determined in Worksheet 3.

If the present worth of the outside venture is less than the HRI's present worth, proceed to diamond 18, otherwise, go to box 14.

(14) Navy Capital Required for Outside Venture? In boxes 1, 2, and 3, an ongoing cost-saving, approvable, outside venture was found available. The question then becomes, is any Navy capital input required? If none is required, proceed with project in box 35. If Navy capital is required, the venture must be evaluated against internal possibilities; proceed to diamond 18 for further evaluation.

(15) Is an Outside Venture Approvable? If in box 3 an outside venture was shown to be approvable, proceed onto box 14. If an outside venture was not acceptable and the recommendation is to keep the existing SWM program, go to balloon 17.

(16) Any Emerging Outside Opportunities? For one of several possible reasons the alternate solid waste management plan studied was found to be one that should not be pursued. At this point, instead of scrapping the whole idea one should research any new technologies that might provide a viable alternative to the current SWM program. If opportunities are found, pursue them by returning to box 4. If nothing appears promising, maintain your current SWM program and go to balloon 17.

(17) Maintain Status Quo. At this point several alternatives in the management of solid waste have been evaluated against current SWM operations. The existing SWM plan was shown to be the most cost effective and acceptable plan of all those considered.

(18) Proceed with Level II Data Gathering. In the preceding sections alternative SWM programs were evaluated and have shown a potential for cost savings over the existing SWM program. To proceed further in the decision process, the reader should familiarize himself with the Feasibility Study presented in this guide. After one has studied this study he can proceed with gathering level II information.

A more accurate picture of the solid waste composition can be obtained by exercising the instructions contained in Appendix A, which is also used by the Air Force (Ref 5). In the next step, WS1 should be updated with the new estimate of the solid waste flowrate obtained using Appendix A.

The National Bureau of Standards has published extensive predictions on the escalation of other energy prices from the "Life-Cycle Costing Manual for the Federal Energy Management Program" (Ref 6). The predicted levelized energy prices for steam from 1985 to 2010 is $13.90 (per MBtu, in 1985 dollars) (Ref 7).

The planner should also read Solid Waste Disposal Alternatives of this report for an update on possible outside SWM options. Next proceed to box 19 for the evaluation of possible uses of energy generated by an HRI.

(19) Can Specific HRI/Energy Fits Be Worked Out? At this point the question becomes, can the energy produced from an HRI be used, and if it can, exactly how will it fit into the existing system. Complete the Energy Demand and Energy Fits worksheets, 2 and 4.

If one or more energy demand systems can be developed to utilize the quantity and type of energy from the HRI, proceed to box 20 to evaluate the economics of each system. In the case where the waste energy cannot be fitted to existing energy demands, proceed to box 16 for an update on any emerging outside opportunities.

(20) Are These Fits Economical? In the last box, one or more energy demand systems were developed to utilize the output energy from an HRI. Each system must be proven to be an economically viable alternative.

For the system to be economically viable, the cost of the energy saved per year must be equal to or greater than the equivalent annual cost of converting the existing system to a system using HRI energy. The conversion may be as simple as routing new steam piping or as extensive as a new system of converting the type of energy produced from an HRI to another energy form.

If any of the systems are determined to be economical, proceed to box 21 to select the best system. If no system is economical, investigate any emerging outside opportunities in box 16.

(21) Compare and Select Best Concept. Will It Work? The planner must now select the most cost effective and suitable system to use the energy produced from an HRI.

Criteria for selecting one system over another are as follows:

a. Does the proposed system meet the needs and requirements of the activity (i.e., provide energy when it is needed, with acceptable reliability), and if so,

b. Is it the most cost-beneficial system?

The last question to be asked about a system designed to provide energy to various energy consuming points is, will it work? If, after a careful study of the system, it appears to meet the Navy's requirements, go to box 22; otherwise, study any emerging outside possibilities in box 16.

(22) Will Navy Fund Project? Funding by the major claimant is based on whether the project is cost-beneficial and if they have the money to meet needs of the project.

At this point, the benefit-cost ratio of the HRI should be examined. A detailed cost-benefit analysis can be accomplished by executing the HRI computer model described later in this report. The information gathered in the second level of the iteration should be used as inputs to the HRI model.

To proceed further with a Navy funded project there must be some indication from Naval Facilities Engineering Command (NAVFAC) that the project is technically and economically endorsable. One should therefore communicate with the cognizant EFD to determine the possibility of obtaining NAVFAC endorsement for energy conservation or facilities improvement funding for this SWM program. If NAVFAC will endorse and the major claimant will fund the project, proceed to diamond 23, if not, drop down to box 24.

(23) Proceed with Level III Data Gathering. A Navy funded project has been developed to reduce the cost of management of solid waste at a Navy activity, and there is money to fund such a project.

Prior to proceeding further in this study, one should quickly review the remaining sections of this manual. This will provide insight as to planning requirements, design concepts, operating experience with existing plants, HRI model analysis and the NAVFAC optimum HRI configuration.

In this third level of iteration, the information gathered in level II should be updated if necessary and verified. Use the NCEL survey method (see "WASTESTREAM CHARACTERIZATION") to determine an accurate characterization of the activity's wastestream. A contractor may be hired to update and verify the information on present SWM costs, nature of solid wastes, and the definition of energy systems. Proceed with diamond 25 after all data has been updated.

(24) Can Concept be Satisfactorily Reconfigured? In the last box it was found that no Navy funds are available for the proposed project as it stands. Can the SWM plan be restructured to meet the Navy's requirements for funding? For example, can the plant be operated with two rather than three units? Again, communication with the EFD would be advisable. If the project can be satisfactorily reconfigured, return to box 22, if not, return to box 16 for an update on any emerging outside possibilities.

(25) Prepare Preliminary Design/Performance/Cost Package. At this point a preliminary design, performance, and cost package needs to be developed.

The HRI cost-benefit model should be run with the level III input data at this point. This run of the model should provide a fine-tuned benefit-to-cost analysis of an HRI. After a preliminary package has been developed, proceed to box 26.

(26) Are Full Service Contractors Available? Investigate the possibility of finding a full service contractor who would be interested in the complete project, from financing construction to the operation of the HRI. If a full service contractor can be found, go to diamond 27 and prepare a request for a technical proposal (RFTP). Proceed to diamond 29 if no full service contractor can be found or if none has expressed an interest in the SWM plan proposed.

(27) Prepare and Distribute RFTP. In the proceeding box, one or more full-service contractors were found who have shown an interest in obtaining a contract from the Navy to build, own, and operate an HRI. At this point one needs to prepare an RFTP for the SWM plan under consideration and distribute it to all full service contractors interested in the project. Proceed to box 28.

(28) Offeror's Terms and Conditions Acceptable? A proposal submitted by a full-service contractor must be evaluated against the initial criteria for the SWM project:

a. Compared to present operations, are cost savings still available?

b. Does it meet the needs of the Navy in SWM?

If these two important criteria are met, are the offeror's terms and conditions acceptable? If all requirements and conditions are acceptable, proceed with the SWM project in the last step of this decision flow diagram, balloon 35. If the terms and conditions are not acceptable and the planner has attempted negotiation with the contractor with no success, proceed to diamond 29 for pursuing the SWM plan within the Department of Defense.

(29) Prepare and Submit DD 1391. No full service contractor was found suitable to provide the services requested, therefore the planner must pursue the project management within the Department of Defense. Prepare DD Form 1391 (item request form) and submit it to major claimant. Proceed to box 30.

(30) Proceed with Navy Financed HRI Project? Will major claimant accept the proposed DD 1391 SWM project as it stands? If the project is acceptable and the Navy should proceed with the alternative solid waste management program, proceed to diamond 31. If the project is not acceptable, go to box 33.

(31) Complete Preliminary Design and Work Package. At this point, proper funding has been obtained from the Navy, preliminary design work has been started, and all systems are go on the alternative SWM program. The preliminary design and work package should be completed before proceeding to the next step, box 32.

(32) Navy-Owned, Contractor Operate? An investigation into the possibility of an outside contractor operating the HRI is recommended at this point. If an outside contractor can be found to operate the HRI to meet Navy's requirement, proceed with the project in the last step, balloon 35. If the project is to be Navy owned and operated, proceed to diamond 34.

(33) Can Concept be Satisfactorily Reconfigured? The alternative SWM project is not acceptable to major claimant/NAVFAC as it stands. Can the project be reconfigured to better meet the Navy's needs, requirements, and purpose? If the project can be restructured, return to box 26 to check whether any full service contractors would be interested in the altered project. If the SWM plan cannot be satisfactorily reconfigured, proceed to box 16 for an update on any outside opportunities that may now exist.

(34) Navy Owned and Operated. No outside contractors were found to be suitable to operate the alternative SWM plan. Proceed with the Navy owned and operated SWM plan in the last step, balloon 35.

(35) Proceed with SWM Project. The final decision step has been reached after the careful examination of the economics and feasibility of an alternative SWM program. The decision tree should have provided a complete preproject analysis of the question whether or not to pursue an alternative solid waste management program. When (if) the planner has reached this point through the steps on the decision tree, the alternative SWM program is well on its way to being implemented.

SOLID WASTE DISPOSAL ALTERNATIVES

In recent years several alternatives to the traditional landfill approach for the disposal of solid waste have been explored. The recovery of materials and energy in addition to reducing the quantity of solid waste are the main objectives in the recent studies and developments in alternative solid waste disposal.

Several alternatives have been explored in the disposal of solid waste. The compaction of solid waste reduces the required landfill area. Although compaction by tractors (e.g., crawler dozers) has been used with landfill technology for many years, a study has shown that landfill compactors with steel wheels are more effective in crushing and compacting solid waste (Ref 8). Waste has also been compacted and bailed to reduce problems associated with loose solid waste. The bailed solid waste has been sprayed with a foam layer to eliminate the need of a dirt fill layer. Composting has been experimented with to provide nutrients to the soil. Either chemical or biochemical processes are used to reduce solid waste to compost. Sewage sludge has also been used as a composting material. Recycling of food waste can provide livestock with feed.

The focus of research in solid waste alternatives is in the area of energy recovery from solid waste. The American Society for Testing and Materials (ASTM) has divided fuel derived from municipal solid waste (MSW) into 7 categories (Table 5, Ref 9). The recovery of energy from MSW begins with raw (unprocessed) solid waste, RDF-1. The next two steps in RDF classes involve the shredding of the waste and the removal of metal, glass, and other inorganics. RDF-2 is the more coarsely shredded, retaining more noncombustibles (potential ash). RDF-3, which is also called "fluff RDF", will have a 30% greater heating value (Ref 10) than unprocessed MSW, due to the enrichment of the combustible function.

By definition, all but 5% of RDF-4, a highly pulverized MSW, will pass through a No. 10 mesh screen. This pulverized RDF form can be essentially regarded as a curiosity, preparation costs render it unmarketable. The next step densifies the pulverized MSW into forms of pellets, slugs, cubetts, or briquettes. This fuel type (RDF-5 or d-RDF) is usually in the form of cylindrical pellets that can be burned separately or in combination with other solid fuels such as coal.

Two other forms of fuels are achievable besides RDF solid fuels. These involve the production of liquid and gaseous fuels, respectively (RDF-6 and RDF-7). Pyrolysis utilizes heat to break down organic materials into a combustible gas, a liquid, and a solid. Medium Btu gas can also be had from solid waste by anaerobic digestion. Utilizing appropriate bacteria in an oxygen-free environment, this process breaks down organic materials largely into carbon dioxide and methane. If the CO_2 is removed, a high Btu gas can be obtained. Both liquid and gaseous fuels derived from solid wastes can be fired in conventionally designed, existing Navy steam generators. Thus, these forms of RDF are not considered in the present guide since HRIs are designed primarily for solid fuels.

Solid forms of RDF have also been co-fired with other fuels (coal, pulverized coal, and oil) in existing boilers. Several combustion systems for energy recovery from RDF have been developed (Ref 11). Generally, most of the systems that have been experimented with and developed to the various stages of the solid waste alternatives discussed have shown less than satisfactory results (Ref 10).

Materials recovery has been examined for the recycle of aluminum, ferrous metals, glass, paper, and plastics. The cost effectiveness of materials recovery is most promising when it is utilized in parallel with energy recovery systems. The metal, glass, and other recycleables can be sorted out of the solid waste during the processing step at a HRI plant. The recyclables can then be sold, assuming a suitable market is available. Whether the recovery of materials is economically worthwhile is dependent on the degree of difficulty in separating each material and its market price which can fluctuate widely.

WASTESTREAM CHARACTERIZATION-FEASIBILITY STUDY

Wastestream characterization is vital to accurate estimation of the quantity and heating value of the incoming solid waste. The potential sources and mass flow rates of solid waste need to be identified to estimate the potential waste fuel energy resource for the entire Navy activity. In level II of the iteration, the composition and quantity of the solid waste can be determined by applying procedures set forth in Appendix B. For level III, NCEL has developed a survey method (Ref 12) to statistically define the average and variance of the quantity and composition of solid waste generated at Navy activities. The survey method recommends taking solid waste samples at random periods 25-30 days per year, thus providing an accurate average of the quantity of solid waste produced at the activity. After the wastestream quantity and variance have been identified, the fuel energy value can be calculated employing the method used at NAS Jacksonville (Ref 13).

Heat recovery incinerators have been shown to become more cost beneficial as the solid waste flow rate increases. The minimum mass flow rate for economical operation of an HRI can vary considerably but an absolute value has been established at 10 tpd (Ref 2). After all the activity waste sources have been identified, an investigation into the possibility of obtaining solid waste from other Government activities can also be conducted. Combining the waste disposal operations of several Government activities could lead to economics not only of scale but through the elimination of duplicative efforts.

As a result of the study of the Navy activity, using the NCEL survey method, an accurate measurement of the composition and quantity of the solid waste that is available at the activity (and possibly from other Government activities as well) can be determined. When a hard design level has been reached, the responsible contractor should verify the wastestream characterization results with an independent study.

Present Disposal Practice

Evaluation of on-going disposal practices a Navy activity is an important step in considering the economics of alternative solid waste management plans.

The quantity of solid waste determined from a survey can be used to update the cost of disposal (Worksheet 1). In addition to evaluating existing disposal costs, the escalation of rates for such solid waste disposal also needs to be estimated. Recent studies have shown that present costs for solid waste disposal could double in the next 10 years (Ref 14). Increased costs are dependent on local factors such as the completion of landfills and opening of more remote ones, legislative restrictions, and labor costs. These local factors should be evaluated to determine the expected escalation of disposal costs. Since a majority of Navy activities use public landfills, the question can best be answered by consulting the Association of Government's (AG's) or Council of Governments (COG's) in which the landfill is located. Practically all AG's have conducted long-term studies on this problem and can provide projected information on the scheduled resiting of landfills. If the Navy activity operates its own landfill, it will doubtless have developed relocation plans, whether these involve another site at the activity or a landfill operated by others. NCEL has also done resiting studies and can be consulted.

Present Energy Status

The present cost of the steam, escalation of steam costs, and the fuel savings available from the HRI need to be obtained for use in the cost analysis section of this manual.

If all the steam is purchased from an outside supplier, the unit cost can be easily obtained. Usually, at least part of the steam is produced by the activity. Determination of a cost per unit ($/lb) of steam produced at the facility will require a more extensive survey and cost calculations.

The escalation of energy costs has been estimated by the National Bureau of Standards (NBS) in Handbook No. 135 "Life-Cycle Costing Manual for Federal Energy Management Programs. Using the escalation of energy prices from the NBS study, a levelized energy price for steam from 1985 to 2010 was predicted to be $13.90/MBtu in 1985 dollars (Ref 7). This estimate for steam energy prices can be used in the HRI computer model at iteration levels II and III or the activity may use its own basis for estimating future energy costs if it can be technically justified.

Conventional fuel savings are a function of the amount and heating value of the solid waste burned, the comparative thermal efficiencies of the fossil fuel steam generator displaced and the HRI, the cost of the fuel replaced, and to what degree the energy from the waste can be utilized. The planner should determine how much conventional energy is saved by the use of an HRI.

Local Factors

Several local factors affecting the costs of construction and operation of an HRI should be taken into account.

Pollution problems caused by HRIs include stack emissions, wastewater, and residual solid waste disposal. Plants smaller than 50-tpd must meet state and local air pollution requirements. All facilities larger than 50-tpd are required to meet Federal particulate control of 0.08 grain per dry standard cubic foot (DSCF) when the dust loading has been corrected to a CO_2 gas flue content of 12%. HRI facilities larger than 250-tpd have to meet the particulate control of 0.08 grain/DSCF and obtain the required permits to construct from the local APC agency, which is a complex process. For the larger category of HRIs, an environmental impact statement may also be required. Bag houses and electrostatic precipitators (ESP) are the industry standard for meeting the particulate control requirements. Current Federal, State, and local pollution requirements should all be studied. Whichever regulations apply, however, they will be promulgated and administered by the local APC district. The Federal and State APC officials may or may not review the local APC authority decisions.

Regulation of all types of polluted water from an HRI is covered by the Clean Water Act. At most Navy activities, the wastewater is discharged to an existing sewer system, or if relatively uncontaminated, such as once-through cooling water, to any local drainage channel flowing to the sea or a nearby river or lake. A study should be conducted into the sewer system's ability to handle additional wastewater, including what the charge to the facility will be for discharging to the sewer.

The third type of pollution is HRI solid residual waste. Both unprocessibles removed from incoming waste and the residue and ash from combustion must be removed from the site. Recyclable materials (i.e., ferrous metals, aluminum, glass) may be retrieved and sold, assuming an appropriate market makes resale economical. HRI ash may not be suitable for disposal at a Class 2 landfill and may have to be delivered to a hazardous-waste (Class 1) landfill, as specified by the State. This determination is usually based on the amount of water-leachable material (particularly heavy metals) left in the ash.

The cost of local labor required to operate the HRI plant should be considered. Depending on the activity's location, this value can fluctuate to a large degree. The use of Navy personnel may apparently reduce labor costs, which could be misleading if overhead costs are not considered. Shipping costs of needed materials also need to be considered, particularly if the site is located away from major shipping points.

Local markets for salvaged recyclable materials should be identified. Selling salvage to this type of market will reduce the cost of disposal of the recovered waste functions, such as iron, aluminum and boxboard.

The choice of the HRI's location is dependent on the location of steam loops, solid waste originating points, and the availability and cost of a suitable HRI site. A cost analysis of the site should be conducted, based on the above four factors, to determine the most cost-effective and suitable location for the HRI plant.

Waste Disposal Practices In Neighboring Communities

At this point it could be beneficial to survey the local solid waste disposal practices which the reader's Navy activity may not be participating in and may even not be aware of. The local communities existing disposal costs will also give a base figure to compare with the Navy's current costs. This survey may also provide some insight into other current technologies in the area of solid waste disposal.

The first stop in a survey of neighboring community's waste disposal practices should be at the public works department in each municipality. These people, who are in charge of refuse collection, will be informed on the local disposal procedures being practiced. They can also provide you with information on any private firms or other municipal departments that may accept refuse for whatever purposes.

Another item to be discussed with the local cities pertains to future possible restrictions on types of items that can be disposed of in refuse that is to be fired in an HRI. Such source control has been in place in some European communities for some time and does decrease the problems associated with the sorting out of oversized and nonprocessible materials and the jamming of charging systems with items that are missed.

While conducting this survey, one should also inquire into how the communities are planning to handle their increasing amounts of solid waste. The cost effectiveness of waste-to-energy concepts increases as the quantity of solid waste increases. Thus, as more and more municipalities look to turboelectric waste-fired steam generators, gas production from refuse, and other methods of recovering energy and decreasing the quantity of refuse to be disposed, the attractiveness of the Navy subscribing to disposal services offered by outside communities increases.

If a future-planned, solid waste system in a neighboring community is open to participation by the Navy on a purchased service basis and is well planned, both parties could benefit from an expansion of operations.

Cost Benefit Analysis

The preliminary feasibility study conducted in the preceding sections of this chapter is designed to provide detailed information to be used in the cost analysis of the HRI. The inputs from the foregoing study include, energy price escalation, energy fits, wastestream characterization, and local factors.

A detailed cost analysis for iteration levels II and III of this manual should be conducted using the Heat Recovery Incinerator Model. This model is an computerized mathematical model designed to aid in the evaluation and comparison of HRIs. It is more fully explained in "SYSTEMS ANALYSIS."

The model is used to compare an HRI to an equivalent fossil fuel plant. Six key parameters make up the output of the Model in the HRI Cost and Performance Report. The output data include: life cycle costs, annual barrels of oil offset, annual quantity of landfill space conserved, savings to investment ratio, and total HRI payback period.

The HRI Model is to be used as a design tool in the final level of iteration. Alternatives in design variables such as capital costs, operation and maintenance costs, solid waste variations, energy use modes and inflation rates can be input to the HRI Model to identify the most cost-effective approach in HRI design.

PLANNING REQUIREMENTS

It is assumed that the feasibility study and cost-benefit analysis from the previous sections have indicated the HRI is a viable alternative to the present solid waste management program. This section reviews the planning requirements for developing an HRI.

NAVFAC must be consulted in reference to HRI project approval. In addition to specific NAVFAC money being available, approval will also be dependent on whether the project serves the best interests of the Navy and if alternative solutions have been adequately considered.

Contracting Options

Several options in contracting the design, development, and operation are available.

Recently, the Navy has been favoring full service contracts in many public works utility areas. Full service contractors are responsible for the complete project: design, development, and operation of the HRI under the Navy specifications. Another contracting option is third-party financing. This refers to an outside party financing the project with a Navy agreement to purchase the energy from the plant owners.

A turn-key project approach employs a contractor to build and test the project. Then he turns the facility over to the Navy in operating condition. One other method used by the Navy is the A&E/general contractor arrangement. Architectural and engineering designs and specifications are developed by one firm and then turned over to a general contractor for construction.

Construction Management Steps

Construction management steps can be broken down into eight essential phases of the HRI plant's construction.

The preliminary design of the HRI plant will consist of the concept definition and its mode of operation (duty cycle, manning energy/mass balances), siting and interconnect arrangement, preliminary engineering development (system lay-out, component/system performance specifications, control diagrams), and the development of cost controls and a project schedule. An excellent guide specification for HRI MILCON projects is Reference 15. The preliminary design of an HRI system should give emphasis to components that require long lead time. Items such as initial site work requirements (particularly easements) should be included among the various components of preliminary design.

State and local authorities should not be consulted to determine the exact procedures required to obtain local construction permits. Instead, EFD environmental specialists should be contacted concerning the need and requirements of filing an environmental impact statement (EIS). Generally an EIS is not necessary for plants under 250 TPD (Ref 5). Most HRI's sized for Navy activities would be included in this category. Your EFD will also furnish instructions concerning requirements for operational and construction permits.

Detailed system design involves the expression of the preliminary design outputs into drawings and specifications representing the as-received, installed or erected components. All phases of project engineering, including civil, mechanical and electrical requirements will be covered. Detailed system design may proceed with the same designer as a refinement of the preliminary design or may involve the second step of a two-step procurement process. In the latter arrangement, the output of the preliminary design work would include a bid package, with invitations sent to general contractors to bid. They or their subcontractors would then be responsible for developing the detailed design inputs for the various components they offer to supply.

Detailed design also involves review of the design criteria by the contractor and development of the best design to meet the criteria. Areas for which criteria are to be met in include: facility, solid waste, energy market, schedule, staffing, and performance and costs. In a developing technology, as in the heat recovery incinerator, the periodic redesign of the system to update the components is essential. Thus, provisions should be made in the detailed system design to facilitate component change-out and revisions.

An outside consulting firm should be retained to do a value engineering (VE) evaluation of the design work. Again, it should be stressed that with a developing technology, an in-depth evaluation of the system's ability to perform cost-effectively as designed is very important. The VE consultant will usually amply pay for his services by spotting and heading off questionable system design features.

Following detailed design and a concurrent VE evaluation of the HRI plant, final specifications and a work package must be developed. This package will contain the detailed specifications, complete NAVFAC-approved drawings and the work schedule the contractor will be required to execute.

The construction of the plant will typically involve a modular HRI unit that is shop fabricated and delivered as a completed structure or that is partly assembled on site. Incinerators that are partly field erected usually incorporate brick refractory structures that must be assembled after the unit is set down but are superior in performance to pre-assembled units with cast refractory furnaces.

The contract must contain very specific, bond-guaranteed performance requirements for the overall system and the critical components thereof. These requirements must be supported by stipulations for corrective actions to be performed where the requirements are not met. Provisions for assessment of liquidation damages for failure to provide timely availability of a working system must be in the contract.

The contract should include provisions for the HRI's start up and testing. The purpose of testing is to evaluate all components of the HRI's system for their ability to perform as designed. Equipment modifications required to ensure fulfillment of the system design specifications or oversights in design should be disclosed by the tests. This modification stage becomes essential if off-performance or irregularities in the system are found during testing. System testing should be done by a third party contractor mutually acceptable to both parties or be done by the Navy (e.g., NEESA).

Plant Operation and Maintenance Requirements

Plant managerial responsibilities will be executed by either a private contractor or the Navy. In either case of course, the overall responsibility will be with the Navy activity commander. A chain-of-command for personnel at the HRI begins with a plant supervisor and ends up with assistant operators. Maintenance of the plant, whether preventive or corrective, will be the responsibility of the contractor, if a full-service contractor is used. If the Navy is operating the facilitiy, then a preventive maintenance system should be initiated so that maintenance routines are identified for operator and other PW personnel. Corrective maintenance should be handled on a case by case basis by the Utilities Department head or the plant supervisor when problems occur.

A local air quality district regulatory board is responsible for setting the standards in air pollution control. The plant supervisor has the responsibility of maintaining the air quality and interfacing with the regulatory agency through the Environmental Officer.

The security requirements for HRI facilities are to limit access to the facility and to provide exterior night-time lighting. The security provided at a Navy activity's perimeter is usually sufficient to restrict access to the HRI facility.

Plans for emergency operation of the facility by Navy personnel should be developed in case the contractor fails to operate the plant and alternative disposal arrangements no longer exist. The contingency operation plan should be complete, including the familarization and training of Navy personnel or civilian employees in the operation of the HRI facility.

The operating conditions (furnace temperatures and steam conditions), quantity and source of solid waste, steam production, personnel utilized, hours of operation (maintenance, break downs, start-ups), materials consumed and other factors should be documented. In addition to providing throughput/output data and thermal efficiency of the plant, detailed documentation of these factors is useful in the future design of HRIs.

HRI DESIGN CONCEPTS

Introduction

In developing technologies, such as heat recovery incinerations, there is considerable probability of the system's equipment becoming outdated before the economic life of the equipment has been reached. To minimize this possibility, the latest state-of-the-art HRI equipment should be specified during the design and evaluation phases.

This section is intended to provide the reader with a broad-brush but comprehensive description of the HRI technology as now practiced in this country and Europe. Most of the major HRI plant design options, including those HRI design concepts that NAVFAC regards as optimum are discussed. The optimum design concepts will be discussed in more detail in a later section.

HRI plants have three operating sections: waste handling, incineration, and heat recovery. The waste handling section receives the solid waste on the tipping floor or in a tipping pit where it is sorted to remove oversized materials. The incinerator design includes a mechanism to feed the fuel to the incinerator, burn the refuse in the furnace, produce a flue gas of the proper temperature, and remove the resulting ash. In the next section, downstream, flue gas heat is recovered in the boiler by one of several possible heat exchange configurations.

Waste Handling

In HRIs that burn only waste produced within the activity, a weigh scale may be used to record the quanity of solid waste received. Platform scales used for this purpose are typically load cell-type with capacities ranging from 30 to 50 tons. Scales are generally 10 feet wide, by 30 to 50 feet in length. Both mechanical and electronic weight measurement systems are used on the scales. The electronic system has the advantage of being the more accurate and can be coupled with a microprocessor to record weights and maintain accounts automatically.

HRI facilities with scales are usually linked to the control room, where one of the operators is assigned to monitor incoming waste trucks. The most attractive scale set-up has a communication system between the truck driver at the scale and the plant operator. This system records the weight of the solid waste automatically and eliminates the need of a weigh house and attendant.

The tipping area configuration is to provide for:

a. Unloading of delivery vehicles.

b. Storage of solid waste before it is processed.

c. Mixing of the waste when necessary to provide a homogenous waste.

d. The removal of oversized items.

e. Feeding of solid waste to the waste processing system (if any) and incineration system.

Two basic approaches are used for receiving and storage of solid waste: unloading vehicle on a tipping floor or having them dump directly into a storage pit. In the United States, the comparatively greater quanity of oversized items allowed in the solid waste usually requires that the waste be unloaded on a tipping floor. Elimination of the oversized items is required to protect the machinery in the feed system. It is practical, however, to have both a tipping floor and pit. In that arrangement, the waste, after being culled of oversized items on the tipping floor, is pushed into the pit.

The most effective tipping floor is so configured that vehicles can back in, deposit waste, and pull out. The waste is then spread by front-end loaders to locate and remove oversized items. The sorted waste can then be stacked to a depth of up to 6 feet for storage or be loaded into the processing system or furnace hopper. Storage areas should be designed to hold enough solid waste to provide continuous operation for at least 2 days of plant operation.

Estimation of the floor area needed can be calculated from the density of spread solid waste (maximum about 200 lb/yd^3 - Ref 16), the depth of solid waste stacked on the floor (average depth 5 to 6 feet), and the percentage of the floor used for storage (approximately 50%). Allow an additional 1,000 square feet for truck maneuvering and tipping area.

The second alternative to receiving and storing solid waste is direct dumping from the vehicle into a storage pit. The pit should be as deep as possible (maximum 20 feet - Ref 17) to reduce the work of the overhead crane in stacking waste. The width of the pit should not exceed 20 feet, and the length is dependent on the quanity of solid waste stored.

Typically, HRI facilities with pit-storage employ an electro-hydraulic bridge crane system with a grapple-type bucket to transfer waste from the pit to the incinerator feed hopper. The transfer system is designed to provide sufficient waste to the incinerator feed system for continuous operation of the HRI. The crane is typically operated from a control room or an air-conditioned booth located above the storage pit.

The storage area is generally an integral part of the HRI's plant structure. Buildings are typically steel frame and sheet metal structures. Vertical clearance in the tipping area should be at least 24 feet to allow vehicles to dump the waste. Providing two 14-foot doors (more doors may be required for facilities over 50-tpd capacities) for the trucks to enter the plant will reduce the congestion of vehicles waiting to dump waste. Walls surrounding the tipping floor should be of well reinforced concrete and should stand at least 8 feet to allow the stacking of waste against them.

Incinerator Design

Fuel Charging. Fuel charging refers to feeding waste to the combustion chamber of the HRI. Charging is achieved by two different methods: vertical gravity fed chutes and hydraulically or pneumatically operated, horizontal rams. Hybrid versions of the two are also in use.

Low profile batch chutes feed waste directly into the incinerator. These batch chutes consist of a hopper, chute, and fire door. The hopper and chute must be large enough to prevent the solid waste from bridging and jamming. Hoppers are generally filled by a bridge crane, but front-end loaders can be used. A fire door at the bottom of the chute retains the trash above the furnace. When the sliding fire door is opened, all the material falls into the incinerator by gravity.

The advantages of the batch chute include: lower capital and maintenance costs, less potential for jams and chute fires, and no feed mechanism is required. The only disadvantage is that the feeding is batchwise, instead of the more continuous feeding achieved by the high-profile mechanisms discussed below. Continuous feeding allows more even control of incinerator temperatures.

The high-profile chute is usually large enough to hold 1 hour's supply of refuse. The refuse is fed to the incinerator by dropping directly onto a moving grate that pulls the refuse into the chamber or by a low-profile ram located at the bottom of the chute that pushes the refuse into the furnace. High-profile chutes have experienced problems with jamming and chute fires, but do provide a solid waste feed to the combustion chamber that is more continuous in effect.

Horizontal ram systems consist of a feed ram, hopper and charging door. Waste is loaded into the hopper by a crane, front-end loader, or a chute. The ram slides along the hopper and forces the waste through the fire door into the incinerator. Both the charging door and ram are activated by hydraulic or pneumatic systems.

Although the ram is used extensively, several problems have arisen from ram charging systems; they include: waste jamming the ram, failures of the hydraulic system, wear and buckling of the hopper from heat and abuse from the front-end loaders during loading, fires resulting from burning waste caught on the ram as it retracts from the incinerator, and ram warpage.

Furnace Configurations

The combustion of solid waste in the primary furnace chamber can be achieved in either a starved-air or excess-air environment. Both methods have been used at Navy facilities. A majority of furnaces have an active grate or ram configuration to move the solid waste and ash through the furnace and also to assist in the combustion process by tumbling the waste. The inner walls are covered with firebrick to protect the metal outer walls from extreme heat. Water-wall fire boxes with refractory-protected bottom tubes are also available from at least one manufacturer.

The excess-air furnace configuration is designed to supply more air to the combustion chamber then the combustion process requires. In this type of furnace air environment, only a single combustion chamber is needed to complete combustion. Combustion air is supplied to the solid waste from below and above the grate. Approximately 80% of the combustion is promoted by under-fire air. In several excess-air furnace configurations, a second chamber is also provided to allow for the combustion of the exiting gases and to permit flyash to settle. Such a second chamber is always employed in starved-air configurations.

The starved-air furnace uses substoichiometric air (less air than required for the combustion process) in the primary combustion chamber. The unburned gas, resulting from the pyrolysis and partial combustion of the waste fuel is then burned in the secondary chamber where excess combustion air is introduced. Theoretically, the gas should combust, but in some cases a secondary burner is required. Starved-air furnaces require tight seals at the charging door and ash removal location to prevent air from leaking into the combustion chamber. An increase in the amount of in-leaking air (to stoichiometric levels) causes a significant rise in the furnace temperatures, and ash slagging problems.

The starved-air furnace characteristically has lower particulate emissions than the excess air system. This is due to the reduced agitation of the ash bed from the lower quantities of combustion air. The compensating effect is that the starved-air incinerator ash will have higher residual carbon in the bottom ash, due to a lower burn-out.

Ash Handling Systems. The ash handling systems are designed to automatically remove the ash from the furnace. Several types of ash handling systems are on the market, but they can be generally grouped into wet and dry systems.

Ash handling begins with the motion of the burning solid waste bed through the furnace on a moving grate or over staged, stationary hearths, each stage equipped with a bottom-travelling ram with a reach extending the edge of its stage. Furnace grates also typically incorporate steps to help in the combustion process by tumbling the solid waste. These grates vibrate, oscillate or rotate and thus push the ash through the incinerator. The ash (siftings) that falls through the grate structure is collected at several locations and separately removed, or is fed to the wet or dry ash removal system.

Wet ash handling systems dump the residue from the furnace grate or hearth into a water quench tank. The ash is removed from the quench tank by a drag conveyor or a dredge configuration which allows most of the excess water to drain back. The ash is then deposited in a container for removal to a landfill.

Wet quench is compatible with facilities where the ash can be disposed of on site or where ash disposal costs are not based on weight. If the landfill cost is based on weight, the wet quench ash system may prove to be less economical than a dry system. The mechanism does tend to leach out water soluble matter, including some heavy metals, making the ash more acceptable for disposal in nonhazardous-classed landfills. Dry furnace ash is usually categorized as a hazardous material.

Except where batch ash removal is practiced, which is seldom, the starved-air furnaces almost always employ wet quench tanks to provide a furnace air seal at the ash removal end.

The dry ash removal system removes the ash without a quench tank or conveyor system. Dry systems deposit the ash directly from the furnace into a chute. The ash is sprayed with water, to reduce the airborne ash dust, and then deposited into an ash disposal container. This system reduces equipment costs and problems associated with the ash removal mechanism, but allows air leakage into the furnace. It can, therefore, only be used on excess-air systems.

Combustion Air/Flue Gas System. In incinerators with grate floors, a large portion of the combustion air is supplied to the chamber under the grate. One fan can supply both the underfire and overfire air. The air flows can be modulated between the plenum of each to control the combustion process. Secondary air is often provided in the last chamber for combustion, or in some cases to cool the flue gas (temperature control). A second fan is sometimes furnished to supply air to the secondary chamber.

All ducts carrying gases at temperatures greater than 450°F are refractory-lined, insulated, and kept as short as possible to minimize heat loss. An induced draft fan, normally on the downstream side of the boiler, draws the flue gas from the furnace.

When combustion gases exiting the furnace are excessively hot, they can be made to by-pass the boiler through a dump stack and prevent possible damage to the boiler and/or unwanted output steam conditions. Conversely, the excess heat can be passed through the boiler if an excess-steam heat exchanger or an atemporator is provided. The latter device sprays water on the hottest section of the boiler steam circuitry while excess-steam heat exchangers cool the steam in forced air heat-exchangers. Either type of excess heat system is more expensive than using a dump stack but may be required in areas where state or local environmental regulations forbid the use of dump stacks or require that and the flue gas be passed through air pollution equipment before venting.

Boiler Heat Exchange Circuitry

Configurations. Boiler heat exchange surfaces transfer the flue gas heat to the working fluid (water and/or steam) in a waste heat boiler, integral boiler, or a combination of the two.

Separate from the refractory furnace, the waste heat boiler us es the hot flue gases from the incinerator to produce the steam or hot water. Two types of heat transfer systems are used: water-tube and fire-tube. Fire-tube refers to the hot gas passing through boiler tubes that are surrounded by water. The opposite configuration is defined as a water-tube boiler, in which the tubes can be more flexibly routed. The fire-tube boiler with the water (heat sink) side occupying the larger volume can better tolerate large heat input changes and thus are better able to handle furnace temperature excursions. Fire-tube boilers are designed to allow clear access at one end of the tubes (i.e., the tube sheet). This access is required because fly ash buildup inside the tubes must be cleaned by brush and at more frequent intervals than the cleaning required for a water-tube boiler. For this reason, the choice of a fire-tube boiler is discouraged.

If the boiler design capacity exceeds 5,000 lb/hr steam flow, a water-tube boiler is more efficient and requires less cleaning maintenance. The water-tube, unlike the fire-tube boiler, can incorporate soot (air or steam) blowers that deploy and retract to blow the ash and soot off closely packed tube arrays at regular time intervals during operation, thus reducing the need for manual cleaning shutdowns.

The actual water-tube configuration varies widely from maker to maker. The most inexpensive boiler circuitry is the single pass arrangement, where the gas travels through the boiler's heat exchange path once before exiting to the stack. A more effective configuration of tubes is the triple-pass boiler. This set-up provides for better utilization of the waste heat, with an increased heat transfer residence time.

Advantages of the waste heat boiler include: comparatively low initial cost, process control adaptability, ease of installation, and reduced susceptibility to erosion.

Integral (water wall) boilers have the advantage of a higher thermal efficiency since much of the radiant heat occurring within the furnace transfers to the working fluid instead of to the refractory. Thermal efficiencies can reach 70% as compared to 55% for incinerators using waste heat boilers. These heat exchangers are 50 to 150% more expensive then waste heat boilers (Ref 16). This is because waste heat boilers are highly design-standardized while the waterwall HRI is a comparatively limited production device.

Superheat is achieved by passing saturated steam through the flue gas with the highest energy content. In most HRI applications hot water or saturated steam is the output, but superheated steam can be generated where line condensation must be minimized. Superheated steam is of course preferred in turbo-electric applications but these usually do not pertain to small-scale HRI's because of the economics.

The availability of boilers used in HRI systems can usually be expected to exceed 95%. The only downtime generally associated with boilers is for cleaning, which can usually be accomplished during scheduled shutdowns.

Feedwater Systems. The feedwater systems that supply the water to the boiler typically include two feedwater pumps. Pumps are usually of the electrically-driven, centrifugal type, although steam turbine-driven pumps can also be used. Pairs of pumps are usually specified and are installed in a parallel arrangement with one in standby.

Raw water treatment can be achieved in house or by contracting out to a company specializing in water treatment. The treatment consists of a water softening system, a chemical metering system, including a mixing and heating tank, and a deaerator. Chemicals added to the feedwater include reducing agent (for removing dissolved oxygen), antifoamer, and anticorrosion compounds. If steam is fed into a distribution system that supplies steam to ships, deionization of make-up water will generally be required to meet NAVSEA steam purity requirements.

Blowdown Systems. All steam boilers have a manual or automatic blowdown and some have continuous blowdown. Typically blowdown water is discharged to a sewer, although drywells and residue tanks are also used. If sewer discharge cannot be arranged, consult the EFD concerning the use of dry wells of residue tanks. Blowdown disposal by either method involves environmental questions.

Air Pollution Control (APC) Equipment*

Particulate Control. If particulate control is required to meet the Federal regulations (0.08 grain/DSCF), the electrostatic precipitator (ESP) can effectively meet the requirements. Baghouses are more efficient and have been successfully demonstrated on municipal solid waste incinerators. Unlike the ESP, however, they impose significant pressure drops (to 10 in., water gauge) and frequently high maintenance. In some states the baghouse is defined as best available control technology (BACT) and ESP's may not be used. Cyclonic cleaning devices, such as the multiclone, and related type APC equipment cannot alone meet the Federal air pollution control requirements when challenged with heavily dust-loaded flue gases. Cyclonic devices may nonetheless be useful in reducing dust loading in the flue gas prior to entering ESPS/baghouses thus reducing the required capacity and cost of the latter. As a matter of policy, the decision to use a specific APC System that fulfills regulatory requirements should be left up to the designer as based on life cycle economics.

The ESP units can control particulates from 0.026 to 0.06 grain/DSCF (corrected to 12% CO_2), which is well within the Federal air pollution control requirements.

Many small-scale starved-air type HRIs do not require any external particulate control in certain jurisdictions. As stated earlier, the starved-air incinerator's particulate emission rate is often low due to low turbulence and gas velocities in the primary furnace.

*NAVFAC DM 3.15 should be consulted for more detailed guidance on design of APC equipment for HRI's.

Gas Emissions Control. The solid waste burned in an HRI is characteristically a low sulfur fuel in which about half the sulfur is "fixed" and cannot gasify. Oxides of nitrogen arise as gas emission control problems when the combustor is operating at much higher temperatures than are typical for a solid waste incinerator. This involves the oxidation of nitrogen in the combustion air - a process that does not occur to a significant extent in the flames of more slowly combusting fuels, such as solid waste. Thus, given the small scale of the HRI and its tendency not to emit gaseous pollutants, control of these species probably will not be required, depending on design and local restrictions. Even so, verification of these assumptions will be required.

Local Regulatory Variations. Under the covering laws of the EPA and the States, local air pollution regulatory districts usually set regulations for the control of particulate matter and gaseous emissions. As an example, Table 6 presents emission standards for California, Texas, and Tennessee as well as the corresponding Federal standards (Ref 18).

The impact of the air pollution regulations on design requirements may range from minimal to very extensive, if not prohibitive. The State's environmental protection agency should be initially contacted for the State's localized particulate and gaseous emission regulations. The planner should then inquire at the local air pollution district having jurisdiction over the HRI site regarding the APC requirements of that district.

Plume Dispersion and Stack Design

Sufficient stack height to provide for adequate plume dispersion should be incorporated. Adequate dispersion can be defined as dispersion of the particulate and gaseous emissions so that they are not in concentrations that will have a negative effect on the Navy facility or surrounding communities.

Proper lightning protection should be installed as required. A complete aircraft obstruction lighting system should also be installed if required by FAA regulations (Ref 19).

Control Instrumentation

Instrumentation and control of HRIs range from relatively simple systems with a few gauges, to very complex control and monitoring systems which include TV monitors. A majority of the HRIs in operation employ a central control panel to allow monitoring of all critical operating conditions from one location. Continuous recording of vital operating conditions is useful in maintaining plant records. Table 7 lists the various controls incorporated in 10 HRIs studied. Annunciator alarms indicate high and low temperatures, pressures, and various conditions of component failure.

Combustion chamber temperature control is usually partially or completely automated. Combustion gas temperatures are monitored with thermocouples in both the primary and secondary combustion chambers. Control of the combustion chamber temperature is achieved by several methods that include: varying the waste feed charging rate, modulating combustion air, trimming or turning up auxiliary fuel burners, and actuating, if necessary, watersprays in the primary chamber.

Combustion chamber pressure control is primarily aimed at maintaining proper combustion (whether starved or excess air) and flue gas draft. Pressures are obtained with sensors within both combustion chambers. Other pressure instrumentation includes the underfire air plenum pressure and auxiliary fuel burner (if any) oil pressure.

Locations and parameters monitored in the heat exchanger section include: inlet/outlet (I/O) flue gas temperatures; working fluid temperature and pressure; feedwater temperature, pressure and flow rate; and boiler water level. Blowdown control is usually a manual operation.

Energy Use and Conditions

The energy generated from the waste heat of HRIs can be utilized in a variety of energy consuming devices.

One of the simplest applications of waste heat is the direct use of hot water or steam in space heating. If activities' current heating system employs space heating using hot water or steam, the HRI's boiler output fluid can easily be controlled to furnish the existing system's required operating line enthalpy.

Air conditioners can also be driven using steam energy derived from waste. Absorption air conditioning systems are designed to utilize steam energy. Heat is applied at the generator section of the absorption cycle to vaporize the refrigerant, typically an aqueous ammonia. The refrigerant then follows the typical refrigeration cycle, through a condenser and evaporator, before returning to the ammoniacal solution in the absorber. The absorption cycle is not as efficient as mechanical refrigeration cycles, but utilizes less expensive energy.

Power generation is another option in the use of steam. Steam entering tubines may be superheated to prevent condensation from occurring in the turbine. However, the combination of superheated steam requirement and expensive power generation equipment makes small-scale power generation uneconomical. The HRI can, however, serve as an auxiliary steam generator to a larger, conventionally-fired unit driving a turbine/generator set.

Other equipment (i.e., steam turbine-driven rotary machinery) and processes can be considered for the utilization of the HRIs output steam.

OPERATING EXPERIENCE

Overview

The experience base presented here has been derived from a study conducted by the Naval Civil Engineering Laboratory (NCEL) of 10 HRIs in the United States and Europe: Consumat HRI design at Ft. Eustis, Virginia; Kelley HRI design at Bayport, Minnesota; ECP HRI design at Ft. Leonard Wood, Missouri; Clear Air HRI design at Waxahachie, Texas; von Roll HRI design at Deauville, France; Sigoure Freres S.A. designs at

Besancon and Millas, France; Cadoux Athanor HRI design at Avesnes, France; Volund HRI design at Videback, Denmark; and Bruun and Soresen design at Korsor, Denmark (Ref 20 and 21).

Tables 7 through 15 contain complete tabulated comparisons of the facility sites, scales, waste processing, receiving/storage, incineration features, heat recovery systems, emmision controls, instrumentation and controls, and overall plant performance.

Plant Performance

Fuel Handling Arrangement. The tipping floor/front-end loader system works best with a back-in and pull-out unloading of waste and stacking walls for efficient space usage. The tipping floor arrangement also allows for more complete sorting of oversized materials. This sorting is required when no control at the source has been established on what types of solid waste may be disposed of in the waste-generating system.

The pit/crane arrangement, used for storage and hopper loading, is easier to operate then the tipping floor/front-end loader arrangement, but does not allow for the reliable sorting of oversized materials and nonprocessibles. A combination of the two is probably the best configuration, even if floor dimensions are significantly increased.

Other advantages of the pit/crane set-up include: (1) the crane operator may be in an air conditioned control room and not exposed to dust and truck and front-loader exhaust as is the front-end loader operator; (2) the crane operator can also monitor the HRI operating conditions of the incinerator through a central control panel; (3) lower cost of housekeeping than for a tipping floor.

The front-end loaders used on tipping floors experienced high fuel consumption and tire wear, and required frequent servicing. These vehicles have a life expectancy of approximately 3 years when used on solid waste tipping floors. The bridge cranes used with pit storage have reported failures, but the down time was typically short and the cost of repairs was moderate.

Stoker/Ram Mechanisms. The HRI feed system has been a major source of downtime because of hopper fires, jamming, and the failure of hydraulic components. Carbon steel hoppers showed signs of wear and buckling from the heat and abuse occasioned during loading by the front-end loaders. Hoppers loaded by cranes showed much less distortion than the hoppers loaded by front-end loaders. Fires caused considerable damage to some hoppers due to the charging ram dragging back burning material out of the incinerator, and from the melting and burning of grease or oil.

Excess horizontal or vertical movement of the ram allows the refuse to jam between the hopper and ram. This excess movement is caused by wear on the ram guide wheels and can be prevented by maintenance and replacement of the wheels when they first show signs of wear.

The refractory on the charging doors experiences extreme cycling from hot to cold as the charging doors are opened and closed. This cycling of temperatures results in damage to the refractory which must then be frequently patched. Air leakage through charging doors is a result of either poor sealing due to warped doors or trash buildup preventing the door from closing completely.

High-profile chutes have experienced jamming and bridging of the solid waste.

Furnace/Boiler. Annual patching of refractory wall was common at facilities that operate on a 5-day cycle. Much less refractory maintenance was required for units that operate on a continuous basis since they did not experience the expansion and contraction associated with noncontinuous operation.

Problems that developed during firing in the primary combustion chamber and hearth or grate include: plugged underfire air injection tubes, slag getting between grate sections, and heat warpage of rams used in the firebox to move the fuel bed towards the ash quench tank.

Maintaining the design temperature inside of the combustion chamber is difficult because of the varying composition (therefore, the heating value) of the solid waste. Table 16 contains theoretical efficiencies of HRI configurations and actual measured thermal efficiencies.

The starved-air units tend to burn large amounts of auxiliary fuel during start-up, operation, and burndown. Excess-air systems do not usually use auxiliary burners except for load ignition and possibly trim. Excess-air combustion chambers demonstrably could operate at fuel loadings between 50 and 120% of name plate rating. Starved-air systems had operational problems controlling excessive primary temperature below 75% and poor burnout above 100% capacity.

An obvious conclusion about heat exchangers is that no one system or design has been preferred in all HRI applications. Each design has its advantages and disadvantages. The fire-tube boiler has the disadvantage that it requires cleaning at least four times more frequently than the water-tube boilers. The advantages of a waste heat boiler system include lower cost, faster installation, ease of process control, and possibly less corrosion. The integral waterwall boiler is the most efficient heat exchange system. Unlike their larger counterparts, which have been notably successful in this country and Europe, the small, water-wall HRI has yet to prove itself. Due to their smaller fire box dimensions, boiler tubes are more closely exposed to the flame and severe corrosion problems have been reported. Protective refractory over such exposed water wall areas has been helpful and further experience wtih the system may result in superior design strategies that will improve the superior efficiency of the water wall HRI available without offsetting penalties.

Feedwater Plant. The major problem associated with feedwater systems has been improper metering of the chemicals. This problem generally results from a lack of operational knowledge (training) of the employees. Few problems were associated with the feedwater pumps.

Air Pollution Control Systems. Variations in the particulate and gaseous emissions occur during typical operation of an HRI. Particulate emissions are high during start-up, shut down, and the start of each charging cycle of the incinerator. No particular operating problems have been reported with air pollution equipment. As is seen in Table 13, however, only half the HRI's studied were so equipped.

Control Instrumentation. No problems were reported on the instruments and control systems of the HRIs during operation.

HRI Waste Handling Systems. The wet ash handling system has experienced several problems during operation. These problems, due particularly to the harsh operating environment of water and bottom ash, include: conveyor belts breaking, chains stretching, chains jamming at the guide sprocket or slides, and floating residues. Repairs of the drag chain are amajor cause of downtime.

Starved-air systems reported 0.45 to 0.60 ton of wet residue per ton of solid waste (ton/ton). The excess-air system reduced the refuse to 0.29 - 0.50 ton/ton of waste fuel. In contrast, where a dry spray ash handling system was used by an excess-air system, the residue was reported to be 0.30 ton/ton of waste fuel. The starved-air incinerator showed 90 to 95% combustion, while the burnout of the excess-air incinerator was greater than 95%.

Quenchwater is generally fed to the local sewer system, and no problems were identified with this practice for these 10 sites.

Reliability, Availability, Maintainability (RAM)

If we assume that a plant operates continuously 5 days a week, availability of that facility is the ratio of the number of hours available for operation out of the 120 hours for operation. The time for start-up, burndown, and routine maintenance are subtracted from the 120-hour period.

The starved-air technologies showed availabilities ranging from 71 to 82%. Modular excess-air facilities had availabilities between 72 to 90%. The field-erected excess-air facility's availability ranged from 75 to 100%. Two Danish facilities of this type, on line 7 and 10 years, respectively, demonstrated availabilities of 90%.

Reliability is the ratio of the available hours minus the unscheduled maintenance to the total available hours for operation.

The starved-air HRI's showed an average unit reliability of 90%. This means that 10% of the planned operational period would be lost due to breakdown. Modular excess-air systems reported reliabilities of 90 to 100%. The field-erected excess air systems had reliabilities of 95 to 100%. This higher reliability was associated with better design features, better quality of material, and preventative maintenance programs.

A facility's maintainability is directly related to its reliability and availability. Starved-air units had several high wear items that were difficult to reach or remove. The maintenance downtime associated with military facilities was longer than for other HRI sites that had an on-site maintenance staff. Improvements in maintainability were made as the staff became more familiar with the facility.

Most of the downtime of all the configurations was associated with the incinerator subsystem, and most of the routine maintenance downtime was for cleaning the boiler. Frequent breakdowns in the incinerator involved the loading hoppers and residue removal systems. The European-designed facilities, which enjoy better quality waste fuel due to collection control, had higher overall RAM results.

Safety

Safety concerns are primarily directed towards the boilers and incinerators. Extensive codes have been developed by ASME for the safety of boilers. All boilers must meet these pressure vessel codes and standards.

Four safety devices on boilers include: flow restricting valves, pressure relief valves, and high and low water level sensing equipment. Pressure relief valves should release steam outside and above the building, away from any location that might injure personnel.

A variety of safety features can be built into the incinerator (Ref 22). The flame-out detector senses when the oil or natural gas burner flame has been estinguished while fuel is still flowing to the burner. This prevents an explosive situation of unburned fuel being pumped into the combustion chamber. Another safety matter is the incinerator's excess heat control. A dump stack is an effective device, if it is allowed by the APC authorities. Other devices used to control excess heat from building up in the combustion chamber are water sprays and secondary air quenches. Doors which allow personnel to enter the incinerator should be lockable and should be equipped with alarms that sound when the door is opened during operation.

Installed fire protection equipment must meet NAVFAC DM-8 and activity regulations. One major fire protection concern deals with fires in the feed hopper. In addition to general sprinkler protection (appropriate for the fire hazard classification assigned to the HRI plant), special fire suppression equipment, preferably an automatic water system with a standby CO_2 system (permanent hose reel system), should be installed near the charging door to extinguish any fire in the hopper.

For safety purposes, the primary controls located in the control room should have override capabilities over any local controls. All controls monitoring critical operating functions should be equipped with lights and alarms to alert the plant operator.

Safety design criteria for equipment should include: covers for moving components (i.e., conveyors, motor shafts/fans, chain drives, etc.); locations of voltages 110V or greater clearly marked; and steam condensate, and blowdown piping, covered with insulation and clearly marked.

Other safety concerns include: dust and smoke control; employee health problems related to handling solid waste; and control of hazardous materials entering the incinerator (i.e., explosives, or large amounts of oil, grease).

Training

HRI facilities employ people with up to four different skill levels: technical, skilled, semi-skilled, and nonskilled (laborers). The plant engineer or supervisor is required to have plant experience or formal training for a supervisory position.

Operating personnel should be trained as to the operating characteristics and functioning of the HRI and equipment subsystems. Start-up and shut-down procedures and control mechanisms and principles should also be included in the training.

Maintenance and operating personnel should be trained in the maintenance requirements of the system and components. In addition to procedures, this training should include the reasons and consequences of maintenance or lack of maintenance. Training should also include recognition of early signs pointing to the need for maintenance.

Semi-skilled personnel and general laborers can be trained on site as required. These people are responsible for charging the incinerator, sorting the solid waste, and general maintenance.

Adequacy of Procedural Documentation

The documentation of guidelines and procedures for the operation, maintenance, and safety of the HRI is important. The following documents should be accessible to the plant engineer or operator:

- User's Guidelines
- Operation and Maintenance Manual
- Troubleshooting Manual
- Emergency Procedures
- Records Keeping Procedures

The user's guidelines and operational manual are necessary for operation of the HRI facility. These should include instructions for prestart-up inspection, start-up, normal operation, and plant shut down. The operating manual should include manuals for all the major subsystems and technical data sheets for all instruments, functional components, and specialty devices. The operating manual should by no means be limited to such documentation. The purchase specification must clearly call out the requirement for a deliverable set of operating manuals that describe, step by step, the requirements for operating the overall system. This set of manuals should particularly explain in full detail the proper use of the control systems incorporated within the HRI plant. A too often observed practice at plants of this type is that operators disable or defeat automatic system control loops and interlocks, resorting to manual control because the automatic control system is not adequately explained in the operating manual and is therefore not understood.

A manual covering the maintenance requirements of all the equipment at the facility should also be required. A schedule for frequency of maintenance and replacement of the equipment will ensure proper maintenance being performed at the required time. The maintenance manual should also include guidelines for regular inspection, calibration, and testing of the control systems.

The troubleshooting manual should contain procedures for troubleshooting of specific components and a section with general plant operation problems.

All plant employees should be aware of the general guidelines provided in the emergency procedures manual, and some of the procedures requiring rapid response or action of personnel on site. Emergency procedures should also include definitive procedures for recovery from abnormal operating conditions which could lead to equipment damage or personnel hazard.

Employees responsible for maintaining records should be aware of the procedures for keeping accurate records of the HRI plant. Records should be kept of normal operating conditions, shutdowns for maintenance and repairs, and costs, including consumable items, parts, labor and equipment.

SYSTEMS ANALYSIS

Introduction

The decisions on whether an HRI is suitable at a given activity, and then what type of HRI should be constructed must be based on reliable data obtained by systematic evaluation procedures. One of the most important of these procedures is the economic evaluation which is used to justify the HRI project. The results from the economic evaluation will be used to decide if and what type of HRI is the most economical. The decision will be based on the capital and operation and maintenance (O&M) costs of the HRI versus the fossil fuel offsets (energy savings), and the reduction of solid wastes (landfill savings).

Under "SYSTEMS ANALYSIS" we will discuss (1) the evaluation procedure (NCEL HRI model) used to calculate the economics of HRI operation; (2) the range of actual benefits and costs achieved at several HRI systems; and (3) the NCEL model parameters that have the strongest influence on the cost/benefit situation.

NCEL HRI Model

The NCEL HRI model (Ref 23) is a computerized mathematical procedure used to determine the economic feasibility of an HRI project. The economic computational procedures contained in the model were based on NAVFAC P-442, the Economic Analysis Handbook (Ref 24). The model consists of three sections: data input, economic computation, and the results report.

The data input section serves three functions: data entry from the user, default data entry, and data formatting for the computational section. The user is required to enter data on HRI construction, operating and maintenance costs; solid waste characteristics such as quantity, energy content, and ash content; landfill disposal and transportation costs; and steam costs. Default data values are available for a number of data categories. These default values were obtained from References 18 and 21 so that acceptable alternative data values could be used if site specific data were missing or inadequate. The data for use in the computational section are formated here; the data format is set through entry onto 8 data screens (Appendix C) which specify or limit the size of the data value.

The economic computation section has two main functions: data verification and result calculation. The data verification procedure confirms that all the necessary data have been input and that the data are in the right format. The result calculation includes statistical and economic analysis of the input data to determine the final parameters necessary for economic justification of the HRI.

The results report serves as the summary of the economic analysis. The results are reported in two forms. First, the life cycle costs of the HRI, boiler, and landfill operations in total dollars and dollars/ton incinerated are listed. Second, the savings-to-investment ratio (SIR) and the payback period in years are listed. In general, an SIR value greater than 1 indicates the HRI may be economically justifiable. If two types of HIRs are being compared, the unit with the greater SIR value is the better alternative.

The HRI model is a useful planning tool during the initial stages of HRI justification, and as a final check once costs are set. It is very important that accurate data, especially for solid waste quantities and HRI performance, be input into the model. The principal economic failures in past HRI facilities have been caused by optimistic estimates of performance and solid waste availability. The original economic estimate should be checked once detailed waste assessment surveys (Ref 12), and detailed design and cost estimates are completed.

The HRI model and instructions are available from NCEL for use on Apple Plus and IIe computer systems. A copy of the program discs and instructions can be obtained by contacting NCEL (Code L71). Alternatively, NCEL can also run the computer program for activities once the appropriate data screens (Appendix C) are completed.

Model Results

The results from the NCEL HRI model will be an approximation of the long-range economics of an HRI system. The approximation is necessary because of the variability of the factors which effect HRI economics, especially interest and inflation rates. The results nonetheless have immediate validity because the input data will be the best currently available, and because the results can be viewed as a general indication of project viability.

There were four assumptions required to calculate the economic results. The principal assumption is that interest and inflation rates will remain constant over the life of the HRI project. This assumption was necessary to simplify the economic calculations. By using conservative estimates of interest (high) and inflation (low) rates, HRI projects that are economical can be ensured. Provisions have also been made to account for the different inflation rates between capital, labor, landfill, and energy costs so that the accuracy of the results is improved.

The second assumption is that HRI performance will match design values. This has not been true in the past, but better units and system designs are now available. Again, conservative estimates of performance values (labor, failures, firing rate, availability, etc.) should be used as a precaution.

The third and fourth assumptions are that solid waste characteristics and energy demand will remain the same. No provisions are made for changes in solid waste quantity, composition, or energy content or steam energy demand. Especially for waste quantity and energy demand, a major decrease would eliminate any potential benefits, so realistic data are necessary.

The average, range and coefficient of variation (CV), of the final economic results for seven incinerators (described below) are listed in Table 17. The data are listed for annual waste incinerated, fossil fuel offsets, landfill conserved, life-cycle costs for the boiler, HRI, and HRI savings in terms of discounted total costs and costs per ton incinerated, SIR, and payback period. The CV determines the accuracy of the average when compared to the actual values measured. A low value of CV CV indicates the mean is very accurate. The seven incinerators were selected from 10 discussed previously that are successfully operating in Europe and America. They range in size from 19 to 47 tpd. The three plants deleted* did not have enough available input data. The data used to calculate the economics of each facility were obtained through site visits and general assumptions about inflation rates and other data. Each facility had an assumed project life of 15 years. This assumption, again, is conservative since Reference 17 specifies a project life of 25 years for steam generators.

The HRIs averaged an annual waste incineration rate of 7,810 tons (31 tpd) or 117,200 tons over the 15-year project life. The actual values ranged from 4,680 to 11,731 tons, with a CV of 0.37. Because of the low values of CV, the mean is fairly consistent with the actual results.

Fossil fuel offsets (FFO) and landfill capacity conserved were 9,125 barrels of oil equivalent (BOE) and 4,830 tons, with CVs at 0.43 and 0.48, respectively. The range for FFO was 3,067 to 13,532 BOE, and for landfill capacity was 2,116 to 8,798 tons. These parameters represent the two saving functions of the HRI. In general, HRIs with large values of FFO and landfill capacity conserved, in relation to HRI cost and size, are the most economical.

The boiler life cycle cost (LCC) is the alternative cost of steam production and waste disposal if an HRI is not available. The HRI LCC should be less than 75% of the boiler LCC, or the project may not be economical. HRI LCC is the cost of operating the HRI over the project life. HRI savings are the investments earned from using the HRI after HRI costs have been recovered. Boiler LCC averaged $4,939,870, which is slightly larger than the average HRI LCC of $4,699,830, resulting in an average HRI savings of $2,637,775. The CVs ranged from 0.40 to 0.42 for the three total LCCs. The unit costs are a more useful measure of HRI economics because the influence of HRI size has been accounted for, resulting in a common basis for comparison. Unit costs were determined by dividing the total LCC by the total waste incinerated. The LCCs for the boiler, HRI, and HRI savings averaged 42.37, 43.23, and $24.05/ton, with CVs of 0.33, 0.43, and 0.74, respectively.

The average SIR for the HRIs was 2.14, with a range of 0.06 to 5.09, and a CV of 0.90. The minimum SIR to achieve an economical HRI project is 1.0. By comparing the SIRs for different types and sizes of HRIs, the optimum/most economical HRI can be designed.

The payback period averaged 10.4 years with a range of 7.3 years to greater than project life, and a CV of 0.31. The payback period is the length of time required before total HRI revenues exceed total HRI

*Wahahachie, Ft. Eustis and Avesnes.

costs. Payback is determined by calculating at which point in time the SIR of the HRI is equal to 1. After payback is achieved, the HRI becomes a benefit producing project with earnings equal to the HRI savings.

In general, HRIs with high values of fossil fuel offsets, landfill conserved, and savings to investment ratio will be economical. Those HRIs where alternative costs (boiler LCC) are less than 75% of HRI LCC, will probably not be economical.

Sensitivity Analyses

The results of the economic analyses have been analyzed for sensitivity to identify those parameters which have the greatest affect on the results. These parameters have been analyzed because minor changes in their values can drastically affect the final results. Realistic values for the most sensitive parameters are, therefore, necessary to ensure HRI economic viability.

In this discussion, we will identify which of the NCEL model parameters are high, moderate, low, and not sensitive to SIR values. SIR is used because SIR is the principal basis of choosing between two or more HRI projects.

Figures 2 to 5 show graphs of SIR versus various ranges of values for 12 NCEL model parameters. These parameters are energy and landfill differential inflation rates, capital inflation rate, capital cost, waste disposal cost, fossil fuel boiler cost, heating value of the waste, HRI thermal efficiency, auxiliary fuels, economic life, wet ash produced, and available storage space. Table 18 lists the initial parameter values and the sensitivity of parameter changes in relation to the effect on SIR. A large sensitivity value indicates that changes in the parameter value have a significant effect on SIR values. The parameters with large sensitivity values need to be accurately determined to ensure HRI economic viability.

The sensitivity analysis was conducted using the NCEL HRI model. The initial parameter values are realistic numbers that have been measured under actual operating conditions. The values for each parameter cover the potential range of numbers which may be experienced at an operating HRI. The initial SIR value is 3.40, and is included as a data point for each parameter in Figures 2 to 5. The sensitivity analysis is conducted by varing one parameter value at a time, running the model, and noting the resultant change in SIR.

The most sensitive parameters were capital cost, fossil fuel boiler cost, solid waste heating value, and thermal efficiency. The capital cost was the most sensitive with a value of 1.32. The capital cost is a major part of the investment costs, and is offset by the waste tonnage incinerated. An increase in capital costs without an equivalent increase in tonnage, will rapidly increase project costs. The other three parameters directly affect the quantity and cost of steam produced, which is the major source of savings for the HRI. The boiler costs with a sensitivity of 1.17 are the value of the fuel saved by using the HRI. The thermal efficiency (sensitivity of 1.15) measures the quantity of energy lost, and the heating value (sensitivity of 1.10) affects the quantity of energy available. A decrease in any of these parameters will decrease the energy savings produced by the HRI.

The parameters with moderate sensitivity are energy differential inflation rate, and the economic life. Energy differential inflation rate is the difference between the general or average inflation rate and the actual energy inflation rate. The energy rate has a sensitivity value of 0.65, and directly affects the rate of change in steam costs. A slow or negative rate of change will eliminate steam cost savings. The economic life affects the quantity of waste incinerated by the HRI with a sensitivity of 0.64. A long economic life means the quantity of tons incinerated increases, and that total costs can be spread over a larger base.

The low sensitivity parameters are landfill differential inflation rate, waste disposal cost, wet ash produced, and capital inflation rate. These parameters had sensitivity values ranging from 0.13 to 0.22, and would have minor effects on HRI viability. The first three parameters affect the cost and/or potential savings from landfill disposal of the waste and ash. Since disposal is a minor part of the costs/savings, these parameters are not very significant. The capital inflation rate affects investment costs over time, but a long project life reduces the significance of this parameter.

Two parameters had no effect on SIR values. These were the use of auxiliary fuels and storage space, each with a sensitivity of 0.0. Both parameters are measures of extra or back-up capability and are used only when the HRI is not operating correctly, or has been shut down.

This sensitivity analysis is by no means an absolute, but is intended as a general indication of the influence critical parameters have on cost benefits. A more detailed discussion of this same subject may be found in Reference 24. All of the parameters are interactive and a major change in one parameter may be offset or exaggerated by changes in other parameters. The key point is that the highly and moderately sensitive parameters should have accurate values so that HRI economic viability can be insured.

Conclusions Reached

The NCEL HRI model is a useful tool for predicting HRI economic viability in the planning and final stages of system design and acquisition. The model is easy to use and provides reliable data for HRI justification.

An HRI system will, in general, be economically viable when interest rates are low, inflation is high, energy and landfill costs are high, and a large quantity of solid waste is available. These parameters have the most effect on economic results. Minor changes in these values can cause major changes in the final results. It is, therefore, necessary to obtain realistic data for these parameters.

The cost and quantity of solid waste available can be determined in a waste assessment method (Ref 12). HRI cost effective operation can be maintained at the required level by following the basic design and recommendations in the next section of this report.

NAVFAC OPTIMUM HRI CONFIGURATION

Introduction

Development of the NAVFAC optimum HRI configuration is the result of 4 years of research into the design, operation, and maintenance of HRI systems. The research has concentrated efforts in three areas: long-term reliability, availability, and maintainability (RAM) analysis of the Navy HRIs at Naval Station (NS) Mayport, Florida, and Naval Air Station (NAS) Jacksonville, Florida; short-term analysis of successful, small HRIs in America and Europe; and general research into HRI operating processes, future trends in energy and landfill costs, and methods of determining suitable sites and accurate design data for HRI application. The basic results of these studies, and a general design configuration for an HRI are discussed here.

Long-Term HRI Analysis. The long-term HRI analysis consisted of two studies. The first study was a RAM analysis of the NS Mayport and NAS Jacksonville HRIs used to predict operational performance and to identify chronic equipment problems. The second was an analysis of the "lessons learned" from the operation of the two facilities.

The RAM analysis was conducted for 3 years at NS Mayport, and 1 year at NAS Jacksonville. The NS Mayport HRI operated moderately well but never achieved design performance levels. The shortfall in performance was caused by design problems in the feed rams, crane, I.D. fan, and feedwater equipment; operational problems with the temperature and air controls, which caused excessive slagging; maintenance problems with excessive ash and slag removal; and planning problems with an inaccurate estimate of solid waste generated (2.0 TPH versus 1.25 actual). The NAS Jacksonville HRI did not perform well or produce a significant amount of steam during its brief operational period. The poor performance was caused by design problems in the flail mill, trommel, storage bin, hydraulic system, feed and ash rams, and boiler; operational problems with the temperature, air, and boiler water level controls; maintenance problems caused by excessive dust levels, inadequate space, and inadequate manpower resources to perform routine maintenance; and planning problems such as an overestimate of solid waste generated, and insufficient building area for equipment and waste receiving functions.

The "lessons learned" study examined the major design and operation problems which occurred at these facilities; and the solutions and recommendations made by HRI personnel to correct these problems. Specific problems were analyzed, and the solutions and/or recommendations to correct the problems are incorporated in this guide.

U.S. and European Small-Scale Incinerators. Of the ten domestic and European incinerators discussed previously, eight were operating at a rate of approximately 50 tpd, which is considered to be the practical minimum requirement for a typical Navy HRI. These eight were studied to determine what design and operational factors were observed at each of the plants; general facility descriptions; and what facility features were considered useful or to be avoided. The general recommendations from this study are also reflected in the following sections detailing the HRI optimum configuration.

General Research. The general research into HRI projects covered subjects in diverse areas such as HRI operating processes, future trends in energy and landfill costs, and methods of determining suitable sites and accurate design data for HRI application. The data on HRI operating processes were used to define the critical parameters affecting HRI operation, so that more reliable and efficient HRI systems can be designed. Trends in future energy and landfill costs were important in proving HRI economic benefits, and HRI preliminary site selection. The site selection and data acquisition methods were based on statistical equations that take into account the variability of the waste to correct a major problem in similar projects in the past.

General System Description

The NAVFAC optimum HRI configuration will be based on a 50-tpd system operating 5 days/week producing low pressure steam for use on the activity. This configuration is based on data from Reference 17. The general statements concerning the 50-tpd configuration can be applied to other HRI sizes by using appropriate size and unit number modifications. This is demonstrated when determining the HRI manpower requirements and economics (see "Manning Requirements" and "Siting") which are based on 50-, 100-, and 150-tpd systems.

There are five factors to be considered in designing an HRI: solid waste quantity, composition, and variation; steam demand; and steam condition.

The quantity of solid waste generated by the activity is important because inaccurate estimates of waste quantity can lead to under or over design of capital equipment resulting in substantial revenue loss. The NCEL HRI model predicts that for every percentage point drop in waste quantity, revenues will decrease by 2%.

The composition of the solid waste in terms of energy content, moisture content, and principal components is important in the design of the incinerator chambers, boiler, and waste processing procedures. Accurate information in these areas is necessary to provide a reliable and efficient HRI with few operational problems.

Solid waste variation will have a profound effect on HRI operating characteristics. Large variations in waste delivery rates may require backup incinerator capability so that waste receipt peaks and lows can be effectively handled. Variations in energy and moisture content can also affect steam production rates.

Variations in steam demand are important in determining the economic viability of the HRI project. An important consideration is to make sure that the existing source of steam is capable of being operated efficiently at a reduced output level after the HRI comes on line. Boiler plants do not respond well to large reductions in baseload when there are swing loads to follow. The steam produced by the HRI should always be required by the activity (i.e., HRI steam production should be less than the activity baseline demand for steam of the same enthalpy output by the HRI). The fossil fuel savings are the major economic asset from an HRI facility.

The steam condition required will of course, affect the design of the boiler. Fire-tube boilers are acceptable for intermittent production of low pressure saturated steam where design capacity is less than

5,000 lb/hr steam flow. Otherwise, the water-tube boiler is preferred as more efficient and requiring less cleaning maintenance.

Solid Waste Receiving, Storage, and Handling System

A possible layout of the HRI plant site and building is shown in Figures 6 and 7, respectively. Elevation sketches of the building are presented in Figure 8. These arrangements are conceptual only and one can expect an A&E's design product to vary somewhat from these representations.

The solid waste receiving, storage, and handling system will take up approximately half of the available space inside the HRI building. The receiving area should be a flat concrete floor, 40 feet wide, 25 feet long, with a ceiling height of at least 24 feet. The receiving area should be accessible through two 14-foot wide doors, allowing two trucks to dump waste at the same time. Manual waste sorting will not be used because of the small size tipping floor, and to reduce labor costs. Trucks should dump the waste directly into the storage pit, and the crane should be used to remove any nonprocessible materials* to a dumpster on the side of the pit.

Implementation of such a receiving arrangement is contingent upon the receipt of solid wastes containing a minimum of oversized and/or noncombustible items. This will require that collections obtained from source categories that consistently discard such items be rerouted elsewhere. It should be noted that if the plant receives a mixture of solid waste containing a large proportion of nonprocessible items, increasing the tipping floor size to allow for the manual sorting of the waste should be considered.

The storage pit area should be 20 feet wide by 65 feet long, which includes spare room for a pit 20 feet wide, 40 feet long, and 20 feet deep, and for a container for nonprocessible materials at the edge of the pit. The pit will have storage capacity for 2 days of solid waste deliveries. To prevent trucks from backing into the pit, a 4-inch diameter pipe should be installed, 1 foot above the floor.

The solid waste will be removed from the pit using a small bridge crane with a four-arm, electrohydraulic, orange-peel type grapple. The crane should have a minimum load capacity of 700 pounds, and a minimum volume capacity of 1 yd^3 based on a 10-minute charging frequency. The crane controls should be placed inside the control room next to a window facing out into the storage pit. The window should have a clear view of the pit, loading hopper, and container for nonprocessible materials.

Incinerator Design

The major components of the incinerator subsystem include: the refuse feeder, a combustion chamber and secondary chamber, grates, combustion air supply system, burners, component drive system, and

*Any oversized waste, whether burnable or not, and smaller noncombustible items that can jam the combustion train, such as motors, automobile wheels, steel rods, etc.

access facilities. Because all the incinerators are integrated systems, the components of the incineration subsystem are (and always should be) procured as a unit from one supplier. A suggested layout of the boiler room is shown in Figures 9 and 10.

The desirable features of an acceptable incinerator are excess-air operation, moving grates, and thick, high-quality refractory. Most of the combustion air is supplied as underfire air with the remaining small quantity as overfire air in the primary chamber. Usually little or no air needs to be added to the secondary chamber, which provides a total gas retention time of 2 seconds at 1,800°F. The grates provide variable, positive movement of the refuse through the incinerator and active agitation of the refuse bed for better combustion. Thick (greater than 8 inches), high temperature (3,000°F minimum), high alumina content refractory backed by good insulation (more than 2 inches) is used. These features combine to provide good burnout of the refuse, high energy recovery efficiency, and an easily controlled operation.

The refuse feeder consists of four major components: the hopper, the chute, the fire door, and a feed mechanism. The hopper has a minimum volume greater than that of the crane grapple, with a minimum bottom opening 4 feet by 4 feet square or 5 feet diameter circular to prevent waste jams. The hopper top should be larger than the open grapple spread. The hopper should be constructed of reinforced steel plate. The vertical chute under the hopper should be 3 feet high, with a horizontal-acting fire door on the incinerator top. Gravity should promote the charging effect. The chute volume should also be greater than the grapple volume. The chute should be refractory-lined reinforced steel plate of the same cross section as the feed hopper bottom. The fire door should be constructed of carbon steel plate with a layer of greater than 8 inches of castable-type refractory. Movement is preferably by a rack and pinion gear system.

Two chambers are normally required to efficiently process the waste. The first chamber combusts the waste at 1,400 to 1,600°F turning the waste into an ash, and releasing a gas. The primary air is supplied as underfire air at excess air conditions. The secondary chamber retains the gases at 1,800°F for about 2 seconds to ensure complete gas combustion and to promote fly ash fallout. Both chambers should have greater than 8-inch thick high-temperature, high alumina content, refactory, backed by at least 2 inches of dense mineral wool insulation or the equivalent. Abrasion-resistant refractory should be used on the bottom sides of the primary chamber up to the maximum height of the refuse bed. Brick refractory is definitely preferred, but castable refractory can be used. Bricks should be hung rather than stacked, so that a few bricks or rows of bricks can be replaced without removing all the refractory. The incinerator shell should be constructed of reinforced carbon steel.

The grates are driven by a variable speed motor located outside the chamber and are made of high temperature nickel/chrome alloy. They should be easy to replace and provide adequate bed agitation. Systems that are known to be susceptible to jamming should be avoided.

The total air flow is modulated to control temperatures, and to turn off during the charging cycle. Both the underfire and overfire air are provided by the same fan. The underfire air is used to cool the grates, and provide combustion air. The overfire and secondary chamber air are used as the main temperature controls.

Two fuel oil burners are used to provide for start-up, for shutdown, and for trim when very low Btu waste is burning. Each burner has a blind flange so that the burner may be removed when not in use. The burners are small, mechanically atomized units with an integral blower. The burners should be manufactured by a regular burner manufacturer and equipped with flame detection safety equipment.

The drive systems for refuse feeders, grates, fire doors, and residue removal equipment may be hydraulic, pneumatic, or rack and pinion. All cylinders should have short strokes; flow controls should be provided when 2 cylinders are used to push one object. External, replaceable oil filters are needed on the hydraulic fluid storage tanks, and slow release valves and accumulators should be included in the piping to reduce hydraulic fluid hammer to the extent possible. All hydraulic runs should be hard piped. If hoses must be used, high quality rigid or flex hose should be specified and all mounts should be vibration isolated. Solid stainless steel cylinder rods and pistons should be used, and be fitted with high temperature and high abrasion-resistant seals, where these are applicable. Double seals can also be used where applicable. The hydraulic or pneumatic unit should be located in a very accessible, dust-free, well lit area.

Easy access to all areas of the unit should be provided to facilitate reaching and removing all parts. Adequate lighting and head room are also required. The access equipment consists of platforms and stairs, personnel doors, and view ports. Safety stairs and platforms are provided for access to all parts requiring maintenance such as motors, relays, burners, thermocouples, pressure sensors, water valves, limit switches, as well as access doors and view ports. The platforms are wide enough (typically 3 feet) for safe passage around the equipment as well as for operation and maintenance uses.

Personnel doors are located so that a man can climb in and have something to step on when entering the incinerator. Do not locate personnel access doors over the residue chute unless provisions can be made for several planks to be installed. The personnel doors should be large enough (36 inches by 24 inches) for a man and required materials (refractory, brick, grates) to enter the incinerator. Personnel doors for the incinerators should be easily sealable using easily replaceable air tight seals. Specify hinged and counter-weighted doors, as required, that swing easily and completely out of the way to permit full internal access. The doors should be lockable and those in critical areas should be equipped with alarms that sound when the door is opened during operation.

Heat Recovery System

The type and size of heat recovery system will be dependent on the quantity of energy released from the solid waste and auxiliary fuel (if any) burned in the incinerator, and on the condition and quantity of steam needed by the activity. The major components of the heat recovery system include the heat exchanger, soot removal and fly ash handling system, blowdown system, excess heat system, I.D. fan, and ducts and stacks.

The quantity of energy recovered from the incinerator will range from 4 to 7 MBtu/ton of waste depending on the HRI's thermal efficiency, and the heating value of the solid waste. The energy recovered can be in the form of hot water, saturated steam, or superheated steam. The maximum temperature of the flue gases entering the boiler should be 1,400°F. Boiler outlet temperatures should be in the range of 400 to 450°F.

Steam condition is set by activity needs. The quantity of steam is determined by the quantity of solid waste incinerated or, perhaps, the activity needs, if this happens to be less than the HRI is capable of supplying.

Heat Exchanger/Boiler. Both fire-tube and water-tube boilers can be used to produce hot water or low pressure (150 psi) saturated steam, although water-tube boilers should be used if design capacity exceeds 5,000 lb/hr of steam flow or superheated steam production is required. Water-tube boilers have higher initial costs, but longer useful life, so lifetime costs may be lower than for fire-tube boilers.

Soot Removal and Ash Handling. Fly ash and soot removal should be provided for by using retractable soot blowers operating on compressed air or steam. The boiler should have large access doors so that personnel access is readily obtained for manual ash removal and tube cleaning. All soot blowers and access doors should be easily accessible from permanent ladders or platforms to reduce the maintenance burden.

Blowdown. Continuous or manual blowdown systems can be used. The blowdown water should be cooled by a water/water heat exchanger. The cooled blowdown water can then be used to maintain the water level in the ash quench tank, with any excess water buildup in the latter being discharged to the sewer via appropriate treatment stages.

Excess Heat Systems. If excess steam must be vented to the atmosphere or condensed, it should be done through a steam muffler or a steam-to-air heat exchanger. The steam muffler reduces the noise of venting steam, and is used at activities which infrequently vent steam. The steam/air heat exchanger is used at activities where excess steam disposal frequently occurs.

Induced Draft (I.D.) Fan. The I.D. fan should usually be installed downstream of the air pollution control equipment and is a centrifugal fan with multi-vaned outlet dampers.

Ducts and Stacks. Any ducts carrying gases over 450°F should be refractory lined and insulated. Those ducts carrying gases below 450°F are only required to be insulated. The stack should be 75 feet tall, double-walled, refractory lined, and insulated. Access to the stack for air emissions testing is required. No dump stack will be required because boiler emergencies will be handled by the feedwater equipment and the steam heat exchanger.

Ash Handling and Disposal

The ash from the incineration process should preferably drop through a refractory-lined chute into a water-filled quench tank. The ash chute will have the same dimensions as the feed chute to prevent jams from large items. The quench tank has an automatic water-level control, and a bottom drain. The water level is maintained by excess blowdown water. The ash is removed from the tank by a dredge, and is directly discharged into a container located outside the building. Replaceable wear plates are installed on the tank and the bottom of the discharge chute. Two roll-off containers are used, each with 24-hour storage capacity and a drain to release excess water from the container. Two containers permit continuous operation of the ash removal system.

Feedwater System

The boiler feedwater system will typically be once through and should consist of a water treatment process and a water-feed system. To reduce capital costs, the water treatment can be provided by an existing steam generating plant or by an HRI-dedicated water treatment process. The HRI-dedicated system will include a softening system with 2 ion exchange tanks (standby tank assumes duty on regeneration cycle), 2 chemical mixing and feeding tanks, and a de-aeration (DA) tank. The DA tank should have a capacity equal to 2 hours of the maximum steaming rate. The water-feed system consists of two electrically driven centrifugal pumps, with one serving as a back up.

Air Pollution Control System

The primary factors controlling the selection of air pollution control (APC) equipment are local and Federal laws, and the size of the facility. Under current Federal laws, HRIs under 50-tpd do not have to meet minimum pollution standards. However, this restriction may not apply under local laws or in the future. Units greater than 50-tpd have to meet a 0.08 grain DSCF particulate standard under Federal law, and acid emission limits in certain states (e.g., California).

The recommended APC device to achieve the particulate standard is an electrostatic precipatator (ESP). If acid emissions are regulated, some form of wet scrubber may also be needed. The APC equipment should be located outside the main building unless severe weather hampers maintenance operations. The equipment should be well protected from the weather, with easy access available for maintenance. An experienced APC firm should be contracted to design, construct, and guarantee the units. NAVFAC TS-15852.2 should be consulted as a source of guidance in preparing ESP procurement specifications.

Other Environmental Protective Systems

Other environmental protective systems might include wastewater treatment, noise abatement, odor confinement, vector control, dust control, fire control, building air purification/ventilation, air conditioning, and visual screening of the plant.

Wastewater treatment, noise abatement, and odor confinement will probably not be major concerns unless very strict local regulations apply. The wastewater pollution potential and flow rate should be small, and discharge will be to sewer systems which in general not have strict influent restrictions. Noise will be confined by the metal building, and unless the HRI is near a housing facility, will not increase ambient noise levels significantly. Odors and disease vectors (insects, rodents) will also be minimal or contained within the building as long as the facility is kept neat, cleaned regularly, and waste is processed through the HRI on a regular basis.

Dust control is an important consideration in HRI design. Excessive dust levels coat equipment, increase maintenance, and create an unhealthy working environment for the employees. The primary dust generation areas will be the storage pit, and dry ash/slag removal activities. The primary dust control system would be to physicially separate the pit from the HRI with walls, and to place the ash disposal containers outside the metal building. An extensive preventive maintenance program for lubricating and cleaning dust from equipment and an adequate ventilation system are additional dust control steps.

Fire control can be handled based on local regulations for water pressure and flowrate. Combustible construction materials should be avoided, and automatic spray systems should be located above the storage pit and in the personnel areas. Dry chemical and CO_2 fire extinguishers should be located at strategic points in the facility, especially at the feed hopper, hydraulic equipment, and in the control room. NAVFAC DM-8 should be consulted for fire protection design criteria.

Ventilation should be based on building and HRI size, local climate, and approximately 5% heat loss from the HRI. For a 50-tpd facility, estimated requirements are 100,000 ft^3/minute using 4 powered roof ventilators. The ventilators should be individually controlled and located above the HRI, with make-up air provided by mechanically controlled louvers on the sides of the building. Make-up air does not have to be tempered.

Heating and air conditioning should be provided for personnel areas and the control room. Independent controls should be used in each room. The heat produced by the electronics in the control room should be included in sizing the air conditioning.

Heating of operational areas to prevent freezing of equipment during nonoperational periods should also be provided for if weather conditions so indicate. The plant arrangement is an excellent opportunity for the application of radiant heating because of the high ventilation rates and the "untightened" nature of the building envelope.

Control Instrumentation

Control and monitoring instrumentation is a vital part of efficient HRI operation and control. The primary monitoring instruments measure temperature, pressure, steam production, electrical use, and control status of systems. Secondary instruments measure equipment run-time, consumable usage, and solid waste delivered and incinerated. Readout instruments are located in the control room.

The main process control is primary chamber flue gas exit temperature which controls waste feedrate and combustion air flowrate and distribution. Primary chamber air pressure also controls the combustion air flow as well as the I.D. fan outlet damper so that a negative pressure is maintained and fire flashbacks are prevented.

Other process controls include using waste feedrate to control the steam production rate and excess temperatures; stoker grate speed to control waste burnout efficiency; and damper actuators to control air flow rate and pressure, and HRI temperatures.

Annunciator warning signals or alarms are installed to indicate equipment stoppage (ash dredge, stoker, or hydraulic rams); low or high boiler and DA tank water levels; high or low gas temperatures in the HRI, boiler, or APC equipment; high steam pressure; and other abnormal operational readouts.

Temperatures are measured at the feed hopper (fire detection), boiler flue gas exit, and APC system flue gas exit to indicate potential process problems. Abnormally high temperatures can indicate fire, process failure, or temperatures which could lead to equipment damage.

High or low electrical usage measured at the crane, I.D. fan, and ESP will indicate occurrence of process or equipment failure requiring operator attention.

Secondary operating instruments include ON/OFF lights for major equipment systems; damper and fire door position indicators; runtime meters on all major pieces of equipment; totalizing meters on make-up water, solid waste incinerated, electrical use, auxiliary fuel fired, and blowdown.

Control switches for each piece of equipment should be located near the piece of equipment (local) and in the control room. All the control functions should be primary to the control room so that the operator can override local controls.

Automatic/Integrated Operation. The charging cycle of the refuse feed system should be run off a timer to ensure a consistent throughput. Combustion air supplies should be interlocked with the fire door so that the fan damper closes when the door is open. There should also be automatic control of auxiliary burners (during warm-up and burn-down cycles), high steam-pressure relief vent, and of dredge (if used) and stoker sequence mechanism. There should be automatic level controls for the steam drum and deaeration (DA) tank water levels, power usage control for the ESP, and boiler feedwater temperature control to prevent cold water shock of and loss of steam flow in the boiler.

Building and Support Requirements

Given a 50-tpd firing rate, the HRI system should be located on a site approximately 160 feet by 225 feet in size. All major equipment, including the receiving and storage areas should be inside a prefabricated metal building about 5,000 ft^2 in size and a minimum of 30 feet in height. This size site and facility furnishes the necessary room for truck traffic, a platform scale, landscaping, and adequate indoors space for the receiving and HRI equipment. The HRI system will require utility connections for water, sewage, electrical, steam and instrument air (if applicable). The water line should have a nominal size of 6 inches. The sewer line should be 4-inch piping. The HRI will require about 400 kVA of power which can be supplied by three 150 kVA transformers mounted in a ground enclosure. The steam and condensate return pipes should have nominal diameters of 6 and 2 inches, respectively.

HRI access from the main road should be provided by a wide, two-lane paved road. The platform scale should have a 30-ton capacity and be at least 50 feet from the main access road. Landscaping and aesthetic building design should be used to improve the appearance of the facility.

Manning Requirements (Management, O&M, Other Support)

The manning requirements for a typical 50-tpd HRI facility are listed in Table 19. Table 19 lists two management and other support personnel (one supervisor and one clerk) who are not located at the HRI site. These personnel are in charge of maintaining the HRI contract (if any) between the activity and the HRI operators.

There are nine O&M personnel who are assigned to the site. One foreman who is in charge of supervising HRI operations and maintaining plant records. There are three operators in charge of actual HRI operation (one per shift) and hourly data records. These operators are assisted by four assistant operators (one per shift, plus one extra), who perform routine inspections and maintenance. The final person is a mechanic who is in charge of all repairs, spare parts stores, and ensuring routine maintenance is completed. He is assisted by the extra assistant operator and performs major maintenance during the 2-day weekend shutdowns.

These personnel requirements should apply for facilities with one HRI unit. For facilities with two units or up to a 150-tpd capacity, an extra mechanic/electrician may be required. For larger units, support personnel manhours will have to increase corresponding to the increase in waste incinerated.

Siting

Siting an HRI is dependent on the facility size, location of utilities and waste source, access roads, and aesthetics. The facility should be located very close to the steam user or header (preferably within 100 feet). The site should not have any unusual terrain characteristics that would drastically increase construction costs. The facility should be located near a good access road that is preferably not a main road of the activity where traffic congestion might result. The aesthetics of the site are important in the acceptance of the facility as a beneficial function. Quality landscaping and building construction will improve the appearance of the site. Refuse delivery and residue removal should be at the rear of the building. The HRI should not be sited in or near a residential area or anywhere on an activity where noise and odor complaints from occupants of nearby facilities might arise.

Estimated HRI System Costs

The HRI system and life-cycle economics are listed in Tables 20 through 27. The economics are based on the standard Navy procedures contained in NAVFAC Manual P-442 (Ref 24). The baseline year for all costs is 1983. Life-cycle costs are determined for three HRI sizes: 50-, 100-, and 150-tpd. These sizes bracket a range of conceivable Navy initiated HRI facilities. Facilities less than 50-tpd may not be economical, those greater than 150-tpd will likely be joint ventures with municipal cities, with the Navy as partner and involving steam generator designs considerably different from those recommended here. For each HRI size, estimates of capital, operation and maintenance (O&M), repair parts, and equipment replacement costs are presented (Tables 20 through 24). Life-cycle economic costs for steam production and landfill disposal are given in Tables 25 through 27 for each HRI size.

The basic economic cost data were obtained from Reference 17. These data were based on the present 50-tpd optimum HRI configuration. To provide economic data for the 100- and 150-tpd HRIs, various assumptions were applied to the 50-tpd data. The 100-tpd unit was assumed to be two 50-tpd units; the 150-tpd was two 75-tpd units. It was assumed that one operator/shift could feed two HRI units, and one assistant operator/shift could maintain two HRI units. The larger HRI units would use a proportionally larger crane system and feed hopper to allow one operator to feed the two HRI units. Equipment costs (capital and replacement) would increase as a function of unit cost x $(\text{scaling factor})^{0.6}$. Unit cost would be the cost at the 50-tpd level. The scaling factor is the increase in throughput in the HRI design incineration rate over the base unit (e.g., for a 150-tpd, the scaling factor would be: 150 tpd/ 50 tpd = 3.0). The 0.6 factor is a typical value for representing economics of scale. Building costs would increase as a function of unit cost x $(\text{scaling factor})^{0.4}$. The 0.4 factor is used because an increase in building size involves very little increase in material requirements, thus reducing cost. Consumables and spare parts costs will increase in direct proportion to size increase because these costs are based on the tons incinerated and the number of units, respectively.

The life-cycle economic computations are detailed as follows:

1. The total annual costs from Tables 21 and 22 are added together, and multiplied by a discount factor to provide 1983 costs (Item 2).

2. The capital costs from Table 20 (Item 1), the total cost from Item 2, and the replacements costs from Table 23 are added together to equal the total HRI life-cycle costs (Item 4).

3. Annual steam production equals waste heating value (Btu/lb) x 2,000 lb/ton x HRI efficiency (0.60 is used in this example) x tons waste incinerated/year. The annual value is multiplied by HRI life to calculate life-cycle steam production in 10^6 Btu units (Item 5).

4. Item 4 divided by Item 5 equals the life-cycle cost of steam production (Item 6).

5. Annual boiler steam costs (Item 7) equal Item 5 x fuel cost/gal ($1.10/gal)/heating value of No. 2 fuel oil (112,016 Btu/gal). The annual value multiplied by the discount factor equals the life cycle boiler steam costs which are avoided by using the HRI to produce steam.

6. Life-cycle costs that must be recovered from waste disposal charges (Item 8) are found by subtracting the boiler costs (Item 7) from the HRI costs (Item 4).

7. Life-cycle disposal tonnage (Item 9) is found by 45 weeks/ year x 5 days/week x 15 years x HRI size in tpd.

8. Life-cycle disposal costs are found by dividing Item 8 by Item 9 to get Item 10 in dollars/ton.

The final results indicate that larger units, which operate as well as small units and have the waste tonnage available, will have much better economics than smaller units. This result is expected because the capital and replacement cost base is allocated over more steam and waste units for larger facilities. However, a key point to remember is that the waste tonnage must be consistently available, or the economic benefits are rapidly lost.

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22. ___________. Contract Report No. 82-033: Safety and human factors engineering analysis--heat recovery incinerators. VSE Corporation, Oxnard, Calif., Sep 1982.

23. ___________. Contract Report No. 84-029: Users manual for the heat recovery incinerator (HRI) model. L.I. Dimmick Corporation, Port Hueneme, Calif., Jun 1984.

24. ___________. Technical Note N-1735: Application of the heat recovery incinerator (HRI) model in determining the sensitivity of plant cost benefits to system techno-economic parameters, by R.M. Roberts and K.T.C. Swanson. Port Hueneme, Calif., Sep 1985.

Table 1. Decision Factors Reference Sheet

Key Inputs Required For Feasibility Study	Decision Diagram Element		Level of Decision Process		
	Level	Element	I	II	III
Costs of SWM system now in use	I II III	5 18 23	Worksheet 1: on disposal costs	Update Worksheet 1 with level II's "Nature of Solid Waste" study	Update and Verify[a]
Nature of solid wastes	I II III	6 18 23	Estimate solid waste quantity from Table 3 or from Naval Activity's own records	Appendix A	Reference 12
Definition of energy system	I II III	7 19 23	Assume a general solid waste energy content	Worksheets 2 and 4	Update and verify[a]
Projected energy costs	I II III	10 18 23	Assume a fixed rate increase for energy costs	NBS Handbook #135	same as Level II
Existing and planned outside solid waste options	I II III	4 18 23	Study of local options	Update on outside solid waste options	Update on outside solid waste options
Benefit/cost analysis of the selected HRI system	I II III	12 22 25	Worksheet 3: Preliminary cost/benefit	Execute HRI model with Level II data information	Execute HRI model with updated Level III

[a]*The update and verify may be accomplished by any outside contractor.*

Table 2. Comparison of Disposal Costs in 1983 Dollars (Ref 1)

Disposal Practice	Range of Total Cost ($/ton)		Average ($/ton)	Number of Activities
	Minimum	Maximum		
Contractor off-base landfill	17.0	47.7	37.4	14
Contractor on-base landfill	21.5	--	21.5	1
PW off-base landfill	47.0	74.2	60.6	2
PW on-base landfill	7.0	22.4	12.1	4
Incinerator	18.0	49.6	36.6	4
Transfer station	24.4	41.1	33.5	3
Total	7.0	74.2	34.3	28[a]

[a]Some activities used multiple disposal practices.

Table 3. Waste Rates in Excess of 15-tpd From Estimates For All Activities in the Naval Establishment

Activity	Estimated Solid Waste Generation Rates (tpd)
NSY Pearl Harbor, HI	127.52
MARCORCAMP Norfolk, VA	108.01
MCB Camp Lejuene, NC	93.93
NSY Portsmouth, VA	89.08
NSY Philadelphia, PA	88.80
NAS Dallas, TX	88.46
NSY Mare Island, Vallejo, CA	81.18
NAVSTA San Diego, CA	73.59
MCB Camp Pendleton, CA	72.13
NSY Puget Sound, Bremerton, WA	70.00
NSY Long Beach, CA	62.63
COMFLEACT Yokosuka, JA	59.33
NAS North Is., San Diego, CA	54.39
CBC Port Hueneme, CA	46.41
MCAS El Toro, Santa Ana, CA	46.00
NSC Oakland, CA	45.52
NSY Charleston, SC	45.49
NTC Great Lakes, IL	44.74
MCAS Cherry Point, NC	42.22
NAS Pensacola, FL	42.06
NATC Patuxent River, MD	40.79
WPNSTA Yorktown, VA	39.82
NAS Jacksonville, FL	37.50
NAS Moffett Field, CA	35.83
NAS Miramar, CA	33.42
NSY Portsmouth, NH	33.31
WPNSTA Charleston, SC	33.15
MCDEC Quantico, VA	32.28
NAS Alameda, CA	32.13
NAS Lemoore, CA	30.34
NAS Oceana, VA	30.00
NAS Whidbey Island, WA	29.48
NIROP Minneapolis, MN	29.28
NAVSTA Subic Bay, RP	29.09
SUBASE New London, CT	28.87
NAS Guantanamo Bay, Cuba	28.86
NAVPHIBASE Little Creek, VA	28.67
NWIRP Bethpage, NY	28.18
NAVWARCOL Newport, RI	27.83
NAS Cecil Field, FL	26.83
SUBASE Bangor, WA	25.82
NAVWPNCEN China Lake, CA	24.59

Table 3. Continued

Activity	Estimated Solid Waste Generation Rates (tpd)
NTC Orlando, FL	24.37
NAS Corpus Christi, TX	23.56
NAS Memphis, TN	23.47
NAVSTA Keflavik, IC	23.06
NAVORDSTA Louisville, KY	23.03
NAVWPNSUPPCEN Crane, IN	22.62
USNA Annapolis, MD	22.50
NAF Atsugi, JA	22.45
COMUSFAC Subic Bay, RP	22.40
NAVSTA Rota, SP	21.44
WPNSTA Seal Beach, CA	21.17
MCAS Iwakuni, JA	20.34
NAVORDSTA Indian Head, MD	20.16
MCLB Albany, GA	19.58
COMNAVDIST Washington, DC	19.31
MCAGCC Twentynine Palms, CA	18.87
NAVFAC Argentia NFLD, CA	18.50
NIROP Pomona, CA	18.27
NTC San Diego, CA	18.18
NAVSTA Charleston, SC	17.30
MCAS Beaufort, SC	16.84
MCLB Barstow, CA	16.84
NAS Brunswick, ME	16.64
NSD Subic Bay, RP	16.51
MCAS Yuma, AZ	16.28
NAVFAC Adak, AK	16.25
NAVUSEAWARENGSTA Keyport, WA	16.17
NAVAIRENGCEN Lakehurst, NJ	15.92
NAVSTA Mayport, FL	15.77
MCRD Parris Island, SC	15.57

Table 4. Waste Rate Data Canvassed From 28 Selected Naval Activities Used in Development of Table 3.

Activity	Quantity (ton/yr)	Cost ($/ton)		How Disposed
		Collection	Disposal	
SOUTHDIV				
NAS Corpus Christi, Tex.	13,800 9,600	107.10[b,c] 30.0[a] 34.8[b,c]	27.50[b] -- 27.5[b]	Contractor off-base
NAS Jacksonville, Fla.	13,800	30.4	--	Contractor off-base
NAVSTA LANT Mayport, Fla.	6,900	49.6	--	Incinerator
NAS Chase Field, Tex.	1,000	36.4	5.3	Off-base
NAS Pensacola, Fla.	36,000	17.0	--	Contractor off-base
NAVSHIPYD Charleston, S.C.	12,590	32.8[c]	11.9	Contractor off-base
NTC Orlando, Fla.	8,750	34.3[c]	6.60	Contractor off-base
NAS Memphis, Tenn.	5,500	36.0[c]	26.3	Contractor off-base
NORTHDIV				
SUBASE LANT, New London, Conn.	4,500	30.0	--	Contractor off-base
NETC Newport, R.I.	5,500	--	24.41	PW off-base transfer station
NAVSHIPYD Philadelphia, Va.	27,600	36.2	--	Contractor off-base
WPNSTA Earle, N.J.	2,880	41.1[c]	6.60	Contractor to off-base resource recovery plant
NATTC Lakehurst, N.J.	6,280	25.1	--	Contractor off-base
NTC Great Lakes, Il.	9,600	53.9	--	Contractor off-base
CHESDIV				
NAS Patuxent River, Md.	6,750	9.40	--	PW on-base
MCDEC Quantico, Va.	6,250 3,750	18.4 26.7	4.0 --	PW on-base contractor off-base
LANTDIV				
PWC Norfolk, Va.	35,000	18.0	--	Incinerator
NAVSHIPYD Portsmouth, Va.	18,000	48.3	--	Incinerator
MCAS Cherry Point, N.C.	12,700 2,300	-- --	 35.0	PW on-base contractor off-base transfer station
CG MCB Camp Lejuene, N.C.	45,000	9.6	--	PW on-base
WESTDIV-Seattle				
NAS Whidbey Island, Wash.	5,000	7.0	--	PW on-base
NAVSHIPYD Puget Sound, Wash.	6,100	39.0	35.2	PW off-base
WESTDIV-San Bruno				
NAS Lemoore, Calif.	4,250	21.5	--	Contractor on-base
NSC Oakland, Calif.	7,860	9.4	27.6	Contractor off-base
NAVSHIPYD Mare Island, Calif.	11,400	47.31	--	Contractor off-base
WPNSTA Concord, Calif.	1,400	107.1[d]	--	Contractor off-base
WESTDIV-San Diego				
MCAS El Toro, Santa Ana, Calif.	11,560	46.7[c]	8.0	Contractor off-base
MCAS Yuma, Ariz.	9,125	25.0	0.0	Contractor off-base

[a] 1982 [c] Includes collection and disposal costs.

[b] 1983 [d] Includes leasing cost for containers.

Table 5. ASTM Categories of RDF Fuels

ASTM No.	Description
RDF-1	Waste used as a fuel in "as-discarded" form.
RDF-2	Waste processed to course particle size with or without ferrous separation.
RDF-3	Shredded from MSW processed to remove glass, metal, and other inorganics. 95% passes through 2-in. mesh.
RDF-4	Combustible waste processed into powder form, 95% passing No. 10 mesh screen.
RDF-5	Combustible waste densified, pellets, slugs, cubettes, or briquettes.
RDF-6	Combustible waste processed into liquid fuel.
RDF-7	Combustible waste processed into gaseous fuel.

Table 6. Emission Standards (Ref 18)

Pollutant	Federal[a]	California[a]	Texas[b]	Tennessee[a]
Particulates 12% CO_2, (gr/SCF)	0.08	0.08	c	0.08
NO_x (ppm)	----	225.0	----	----
SO_x (ppm)	----	300.0	----	----
CO (mg/m^3)		d		
Ash	NH[e]	H[e]	NH[e]	NH[e]
Odor (control)	Yes	Yes	Yes	Yes
Smoke (control)	Yes	Yes	Yes	Yes
Opac. (%)	20		30	

Notes:

[a]Applies >45 metric tons.

[b]Multi-chamber incinerator required.

[c]0.3 lb/MBtu, or approx. 0.06 gr/SCF.

[d]Some counties in Southern California have standards for these pollutants (e.g., Ventura).

[e]Proper disposal required - no odor or nuisance problems (H = hazardous; NH = non-hazardous).

Table 7. Comparison Features of HRI Facility Site Layout and Design

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Site Layout										
Landscaping	Good	Minimal	Minimal	None	None	Excellent	Good	None	Good	Fair
Screening	None	None	None	None	None	Trees & fence	Trees & fence	Trees	None	None
Traffic pattern	1-way loop	2-way	1-way loop	NA	2-way	2-way	2-way	2-way	2-way	2-way
Roads	Good	Good	Good	NA	Good	Excellent	Excellent	Fair	Good	Good
Lighting	Good	Good	Good	Good	Good	Excellent	Excellent	Fair	Good	Good
Drainage	Good	Poor	Poor	Good	Good	Good	Good	Fair	Good	Good
Access control	6-ft fence	6-ft fence	None	Interior only	Fence	Fence	Fence	Farm fence	Fence	Part fenced
Building Design										
Maint. work area	Small	Small	Small	NA	Good	Good	Good	Fair	Good	Good
Storage space	Good	Good	Good	Fair	Good	Good	Good	Fair	Good	Good
Utilities										
Heating	Personnel areas only	All areas	All areas	Poor	Office & shower only	Office, lab,& shower only	Office & showers only	Office & shower only	Personnel areas only	Personnel areas only
Air conditioning	Personnel areas only	None	None	None	None	Personnel areas only	None	None	None	None
Ventilation	Poor	Poor	Good	Good	Good except pit	Good except pit	Good	Poor	Good	Good
Lighting	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Employees Facilities										
Restroom	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shower	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lockers	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Maintenance Access										
Receiving	Good	Good	Good	Good	Good	Good	Good	Fair	Good	Good
Waste feeding	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Incin. primary chamber	Good	Good	Chamber/good Pit/poor	Good	Good	Good	Good	Good	Good	Good
Incin. secon. chamber	Good	Good	Good	Poor	Good	Good	Good	Good	Good	Good
Boiler	Fair	Good	Good	Fair	Good	Good	Good	NA	Good	Good
Water treatment	Good	Good	Good	NA	Good	Good	Good	NA	NA	NA
Emission control	NA	NA	NA	NA	Good	Good	Good	NA	Good	Fair
Instrumentation	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Hydraulics	Poor	Poor	Poor	Good	NA	Good	Good	Good	Good	Good
Residue removal	Poor	Poor	Around tank/ good In tank/poor	Good	Good	Good	Good	Good	Fair	Good

NA = Not applicable

Table 8. Comparison of Platform Scale Features at Ten HRI Facilities

Design Data	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Length - ft	50	50	30	NA	NA	33	35	NA	33	NA
Width - ft	10	10	10	NA	NA	10	12	NA	10	NA
Capactiy - tons	50	50	50	NA	NA	45	44	NA	ND	NA
Weight system (lever, load cell)	Lever load cell	Load cell	Load cell	NA	NA	Lever balance	Lever balance	NA	ND	NA
Recording (auto/manual)	Semi	Semi	Semi	NA	NA	Manual	Semi	NA	Auto	NA
Intercom	No	No	No	NA	NA	No	Yes—w/plant	NA	TV camera/horn	NA
Scale	Yes	No	No	NA	NA	Yes	Yes	NA	No	NA

NA = Not applicable
ND = No data

Table 9. Comparison of Waste Processing Systems at Ten HRI Facilities

Description	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videback
Waste Composition										
Residential	60%	~20%	70%	---	80-90%	99%	95%	100%	60%	30%
Light industrial	---	~10%	10%	95%	5-15%	1%	5%	---	20%	30%
Commercial	40%	~10%	20%	5%	5%	---	---	---	20%	---
Other	---	~60% woodchips	---	---	---	---	---	---	---	40% Purch. waste
Processing Systems										
Source separation	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sorting	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
Shredding	No	Yes	No	No	No	No	No	No	No	No
Container/yd³ or cy	Yes/ND	No	Yes/30	Yes/40	No	No	No	No	No	Yes/ND
Amount Removed										
Tons per day	<1	.4	ND	ND	None	None	None	None	None	<1
Yd³ per week	ND	ND	30	60	None	None	None	None	None	ND

ND = No data

Table 10. Comparison of the Receiving/Storage Systems at Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Tipping Floor										
Gross area (ft^2)	5000	8832	7200	400	NA	NA	NA	NA	NA	1118
L × W (ft)	50 × 100	92 × 96	72 × 100	40 × 10	NA	NA	NA	NA	NA	43 × 26
Refuse storage area (ft^2)	2000	4592	3600	ND	10	NA	NA	NA	NA	676
Loader-diesel/gas	Diesel	Gas	Diesel	NA	NA	NA	NA	NA	NA	Diesel
Pit										
Volume (yd^3)	NA	NA	NA	NA	200	900	2616	150	732	164
L × W × D	NA	NA	NA	NA	25 × 13 × 17	60 × 20 × 18	120 × 30 × 35	40 × 11 × 11	25 × 14 × 28	26 × 17 × 10
Grapper cap. T/yd^3	NA	NA	NA	NA	.4/.8	ND/1.3	ND/2.5	.2/.8	ND/1.3	4/2
Crane - man/semi/auto	NA	NA	NA	NA	Manual	Auto	Auto	Manual	Semi	Semi
Facility										
Heating - Btu/hr	ND	883,600	145,000	ND	None	None	None	None	None	None
Vent - No./CFM	2/24,000	6/3100	3/12,400	3/6000	None	None	3/ND	4/2000	2/ND	None
Lighting - artificial	8-400W 12-250W	24 × 250W	20-400W	12-250W	ND-500W	(7)40W (3)500W	(18)ND	(3)150W	(5)80W	(16)125W
- natural	(8)roof	None	(4)roof	None	(8)wall	(3)roof	(9)roof	None	(15)roof	(4)roof
Fire Protection										
Type	Hose	Hose/CO_2	Sprinkler Hose/20 lb ABC	Sprinkler Hose/10 lb ABC	Hose 2 lb ABC and CO_2	Hose 10 lb	Hose portable	None	Sprinkler 13 lb ABC	Hose 5 lb ABC
No.	(3)1 1/2"	(1)1 1/2"/3	(1)1/2"/2	(1)1 1/2"/1	(1)3/4"/2	(2)1 1/2"/1	(1)1 1/4"/4	None	NA/2	(1)1 1/4"/2
Access 1-way/2-way	1-way	2-way	1-way	NA	1-way	1-way	1-way	1-way	1-way	1-way
No. of doors	2	2	2	2	2	4	8	2	2	2

NA = Not applicable
ND = No data

Table 11. Comparison of Incinerator Features at Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Operating Mode CA/EA	CA	CA	CA	CA	EA	EA	EA	EA	EA	EA
Unit Capacity/TPH	1.0	1.0	1.6	1.0	2.2	2.75	2.0/3.3	1.0	2.2	2.2
No. of Units	2	3	2	2	1	2	2/1	2	1	1
Refuse Feeder										
Type	Ram	Ram	Ram	Ram	Chute	Chute	Chute/ram	Ram	Chute	Chute
Volume/yd^3	4.7	2	1.7	4	6	4.7	15	5	ND	~5
Operator	Hyd	Hyd	Hyd	Hyd	Elec	Hyd	Hyd	Pneu	Hyd	Hyd
Primary Chamber										
Hearth/grates	Grates	Hearth	Hearth	Hearth	G rates	Grates	Grates	Grates	Grates	Grates
Overfire air hp	NA	NA	NA	NA	NA	ND	N/D	NA	3	7.4
Underfire air hp	3	5.75	5	10	7.4	20	60/74	6	30	20
Refractory										
Type	Castable	Brick castable	Brick castable	Brick	4 6% Al cast	46% AL & Carbor brick	Brick	Brick castable	Brick	Brick
Thickness	5"	5"	4 1/2 - 6"	6"	~10"	17"	9 1/2"	3.3 - 9"	9"/7"	7"
Insulation thick	4"	2"	1 1/2"	2 1/2"	2 - 1/2"	None	2"	4" - 5"	2"	5" - 3" air gap
Burner Btu/hr	4.15×10^6	ND	0.5×10^6	ND	1.19×10^6	ND	None	None	ND	None
Secondary Chamber										
Vol. ratio -SC:PC	1:1	1:1	1:2	1:1	1:1	NA	NA	1:1.8	1:1	NA
Combustion air	Yes	Yes	Yes	Yes	No	NA	NA	Yes	Yes	NA
Refractory										
Type	Castable	Castable	Castable	Castable	Castable	NA	NA	Brick	Castable brick	NA
Thickness	5"	5"	5"	3"	10"	NA	NA	3" - 9"	7" - 9"	NA
Insulation thick	4"	2"	2"	1"	2 1/2"	NA	NA	4" - 5"	2"	NA
Burner Btu/hr	4.25×10^6	ND	2.5×10^6	ND	None	NA	NA	None	None	NA
Power System										
Type	Hyd	Hyd	Hyd	Hyd	Elec	Hyd	Hyd	Pneu	Hyd	Hyd
Horsepower	2@25	3@7 1/2	2@15 1@3	2@10	NA	2@7	3@ND	2@ND	3@ND	2@4
Residue Removal										
Ejection										
Quench	Wet	Wet	Dry/wet	Dry	Wet	Wet	Dry/wet	Dry	Dry	Dry
Removal	Drag chain	Drag Chain	Drag chain	Cart	Dredge	Drag chain	Convey skip hoist	Cart	Conveyor	Conveyor
Storage										
Type	Container	Container	Container	Cart	Container	Container	Bunker	Cart	Silo	Container
Capacity/yd^3	7	16	40	1	10	8	1000	1.5	ND	2@40
Residue: Feed ratio	0.6:1		0.5:1	0.1:1	0.5:1	0.45:1	0.3:1	0.3:1	0.3:1	0.3:1
Burnout %	90	90	90 to 95	95	95	95	95	95	95	95
Incinerator	Yes	Yes	Yes	No	No	No	No	Yes	No	No
Refractory	Yes	Yes	Yes	NA	NA	NA	NA	Yes	NA	NA
Shell	Steel	Steel	Stl. Steel	NA	NA	NA	NA	CORTEN	NA	NA

NA = Not applicable ND = No data

Table 12. Comparison of Heat Recovery System Features at Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Rayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
No. of Units	1	3	1	2	1	2	3	NA	1	1
Rating	20,359 lb/hr	6800 lb/hr each	8200 lb/hr	10,000 lb/hr each	4500 lb/hr	13,200 lb/ hr ea	27,750 lb/hr total	NA	36 × 10^6 Btu/hr	12.7 × 10^6 Btu/hr
Quality	250 psi sat.	108 psi sat.	150 psi sat.	13 psi sat.	175 psi sat.	175 psi sat.	353 psi sat. @482°F	NA	87 psi water @ 240°F	147 psi water @ 203°F
Type boiler	Fire tube	Fire tube	Water tube	Fire tube	Water tube	Fire tube	Water tube	NA	Fire tube	Water and fire tube
No. passes	1	3	6	3	3	1	1	NA	2	4
Radiant inlet	No	No	No	No	Yes	No	Yes	NA	No	Yes
Superheat	No	No	No	No	No	No	Yes	NA	No	No
Soot blowing	No	No	Air	Air	Steam	No	Steam	NA	No	No
Ash removal	None	None	Manual	Manual	Manual	Conveyor	Conveyor	NA	None	Convyor
Excess heat/ bypass	Dump stack	Dump stack	Dump stack	Dump stack	Heat exchanger and bypass	Heat exchanger	Heat exchanger	NA	None	None
Blowdown	Manual	Manual	Auto/manual	Manual	Auto/manual	Manual	Manual	NA	NA	NA

NA = Not applicable

Table 13. Comparison of the Emission Control Systems at Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Type	Controlled air	Controlled air	Controlled air	Controlled air	Multiclone	ESP	ESP	Quiescent chamber	Multiclone	ESP
Emission Std (gr/DSCF @ 12% CO_2)	0.2	0.2	0.14	0.1	0.45	0.11	0.11	0.45	0.11	0.11
Tested emissions	0.123	0.13	0.07	0.102	ND	0.06	0.04	0.28	ND	0.026
Ash removal	NA	NA	NA	NA	Manual	Conveyor	Conveyor	NA	Pneumatic	Conveyor

NA - Not applicable

Table 14. Comparison of the Instrumentation and Controls at Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
General Facility										
Central control panel	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control room	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Graphic display	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes
Water meter	No	No	No	No	Yes	No	No	No	Yes	No
Electric meter	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Auxiliary fuel meter	Yes	No	No	No	No	No	No	No	No	No
Incinerator System										
Temperature										
Primary chamber	I,A,C	I,A,C	I,C	I,C	I,A,R,C	I,A,C	I,A,R	I,R	I,C	I,A,C
Secondary chamber	I,A,C	I,A	I,A,C	I,C	I,A,R	I,A	NA		I	
Pressure										
Primary chamber	C	I,C	I,A,C	I	I,A,R,C	I,C	C		I,C	I,A,C
Secondary chamber			C	I	No	NO	I,A			
Auxiliary fuel								NA	NA	NA
Primary chamber	I	I,A,M	I,A,M	I,M	I	I				
Secondary chamber	I	I,A,M	I,A,M	I,M			I,A			
Position										
Feeder	I,A	I,A	I,A	I,A	I,A	I,TV	I,A		TV	TV
Grates	I,A		I,A		I		I,A			I,A,TV
Ash removal	I,A	I,A	I,A	I	I	I,A			I	I,A
Heat Recovery System								NA		
Temperature										
Flue gas		I				I,R	I,R		I ·	I
Steam/hot water				I						
Feedwater		C				C	C		I	I
Pressure										
Steam	I,C	I,C	I,C,	I,C	I,R,C	I,C	I,C		I,C	C
Feedwater				I	I,A					
Flow rate										
Feedwater		M	M	I						M
Steam/hot water	M	M	M	I,R	I,R	I	I,R		M	M
Level										
Boiler drum	I,A	I,A	I,A	I,A	I,A	I,A	I,A			
Emission Control	NA	NA	NA	NA				NA		
Opacity					I,R	I	I,R		I,A	
Temperature						I,A	I,A		I	I,A
Pressure									I	
Malfunction					I	I,A	I			I
Ash removal						I				I,A

I = Indicating
A = Alarm
C = Control point
R = Continuous recorder
M = Totalizing meter
ND = No data
NA = Not applicable
TV = Television

Table 15. Comparison of the Overall Plant Performance for Ten HRI Facilities

Feature	Waxahachie	Ft. Leonard Wood	Ft. Eustis	Bayport	Millas	Deauville	Besancon	Avesnes	Korsør	Videbaek
Design capacity TPW	250	280	200	240	40	132	174	48	265	327
Tons processed TPW	109	218	125	102	---	15,400	133	---	196	221
Plant avail. %	72	89	82	71	>90	75	100	80	89	91
Steam output lb/hr	ND	7500	ND	8000	~4000	9700	27,750	NA	9.1×10^6	14.3×10^6
Steam output lb/lb	ND	2.9	3.08	4.0	2.4	2.28	2.5	NA	---	---
Oper. labor hr/T	3.33	1.75	.86	0.94	0.87	1.08	0.5	0.55	1.81	0.92
Maint. labor hr/T	1.2	1.79	.63	0.17	0.36	0.55	0.31	0.27	0.29	0.33
Elect. Kwh/T	81	46.5	44.6	16.3	20	55	28.4	5	42.8	42
Aux. fuel Btu/T	29,000	1.12×10^6	1.12×10^6	0.46×10^6	70,000	28,000	None	None	None	None
Plant reliability %	90	100	90	95	>95	95	<99	~100	98	100
Residue T/ton	ND	.44	.5	.04	.5	.45	ND	ND	.42	ND
Purch. waste T/ton	NA	.58	NA	NA	NA	NA	NA	NA	.08	ND
Water & sewer gal/ton	102	102	102	40	308	165	ND	ND	.79	ND

ND = No data
NA = Not applicable

Table 16. Theoretical and Operating Thermal Efficiencies of HRI Plants (Ref 5 and 16)

HRI Plant	Design η (%)	Actual Operating η (%)
Modular Starved-Air	50	42-50[a]
Modular Excess-Air	60	---
Field-Erected Refractory Wall Excess-Air	60	53-60
Integral Waterwall Excess-Air	70	---

[a]These units showed that efficiencies deteriorated with the age of the plant.

Table 17. Statistical Data for the Final Economic Results of Seven HRI Facilities

Parameter	Average	Range		Coefficient of Variation
		Low	High	
Annual Waste Incinerated (tons)	7,810	4,686	11,731	0.37
Fossil Fuel Offsets (BOE)	9,125	3,067	13,532	0.43
Landfill Conserved (tons)	4,830	2,116	8,798	0.48
Life Cycle Costs				
Boiler				
Total ($)	4,939,870	1,745,320	7,171,150	0.42
Unit ($/ton)	42.37	24.83	65.62	0.33
HRI				
Total ($)	4.699,830	2,890,770	8,119,570	0.40
Unit ($/ton)	43.23	23.11	77.90	0.43
HRI Savings				
Total ($)	2,637,775	93,360	4,402,400	0.66
Unit ($/ton)	24.05	1.33	52.66	0.74
Savings to Investment Ratio (SIR)	2.14	0.06	5.09	0.90
Payback Period (yr)	10.4	7.3	>Project Life	0.31

Table 18. Sensitivity and Initial Parameter Analysis

Parameter	Initial Value	Sensitivity[a]
Energy Inflation,%	5	0.65
Landfill Inflation, %[b]	5	0.13
Capital Inflation, %	5	0.16
Capital Cost, $M	2.1	1.32
Disposal Cost, $/ton	15	0.22
Boiler Cost, $/MBtu[c]	9.0	1.17
Higher Heating Value, Btu/lb	5,000	1.10
Thermal Efficiency, %	55	1.15
Auxiliary Fuels, Btu/lb waste	210	0.0
Economic Life, yr	15	0.64
Wet Ash Produced, ton/ton waste fuel	0.45	0.18
Storage Space, tons	150	0.0

[a]Sensitivity equals the percentage change between SIRs from middle to high values divided by the pergentage change between parameter values from middle to high.

[b]These curves were nonlinear. Sensitivity was determined by taking the average of the sensitivities between the middle to low and middle to high.

[c]The cost of operating an equivalently sized, fossil-fuel-fired steam generator.

Table 19. Recommended Staffing and Annual Manhours to Operate a 50-tpd HRI Facility, 5 Day/Week, 24 Hour/Day[a]

Position	No.	Annual Manhours	
		Operation	Maintenance
Supervisor	1[b]	260	260
Clerk	1[b]	260	260
Foreman	1	1,550	530
Operators	3	6,240	---
Assistant Operators	4	5,824	2,496
Mechanic	1	208	1,872
Total	11	14,342	5,418

[a]Assumes residue removal contracted to private company.
[b]Not on site.

Table 20. Capital Costs

[Baseline year - 1983]

Item	Total ($)[a] for --		
	50-tpd HRI	100-tpd HRI	150-tpd HRI
Scale[b]	80,000	80,000	80,000
Crane	55,000	83,000	106,325
Incinerator	1,100,000	1,667,290	2,126,500
Residue system	100,000	151,570	193,320
Boiler	400,000	606,290	773,375
Building[c]	700,000	923,655	1,086,290
ESP	200,000	303,145	386,635
Instrumentation	62,000	93,975	119,860
Engineering[d]	162,000	234,560	292,340
Total	2,859,000	4,143,850	5,164,645

[a]Cost at 50 tpd x $(\text{No. units})^{0.6}$

[b]Only 1 scale is needed

[c]Cost at 50 tpd x $(\text{No. units})^{0.4}$

[d]6% of the total of all other costs

Table 21. Operation and Maintenance Labor Costs

[Baseline year - 1983]

Personnel	Rate ($/hr)	50-tpd HRI			100-tpd HRI[a]			150-tpd HRI[a]		
		No.	Manhours	Cost ($)	No.	Manhours	Cost ($)	No.	Manhours	Cost ($)
Supervisor	15	1	520	7,800	1	580	8,700	1	600	9,000
Clerk	11	1	520	5,720	1	580	6,380	1	600	6,600
Foreman	13	1	2,080	27,040	1	2,080	27,040	1	2,080	27,040
Operators	12	3	6,240	74,880	3	6,240	74,880	3	6,240	74,880
Assistant Operator	10	4	8,320	83,200	4	8,320	83,200	4	8,320	83,200
Mechanic	13	1	2,080	27,040	1	2,080	27,040	2	2,080	27,040
Assistant Mechanic	11	--	---	---	1	2,080	22,880	1	2,080	22,880
Total		11	19,760	225,680	12	21,960	250,120	12	22,000	250,640

[a]Assumes 1 person/shift operating crane full time.
Assumes 1 person/shift performing maintenance full time.

Table 22. Consumable Cost

[Baseline year - 1983]

Consumables	Unit Cost ($)	Usage/Ton of Waste Received	Cost for 1 Year [a]		
			50-tpd HRI ($)	100-tpd HRI ($)	150-tpd HRI ($)
Electricity	0.06/kW-hr	50 kW-hr/ton	33,750	67,500	101,250
Auxiliary Fuel	1.10/gal	0.2 gal/ton	2,475	4,950	7,425
Residue	12.25/ton	0.45/ton	62,015	124,030	186,045
Nonprocessible Waste	33/ton	0.025/ton	9,280	18,560	27,840
Total			107,520	215,040	322,560

[a]Based on 45 weeks/year of waste deliveries, 5 days per week, and includes downtime and waste nonavailability.

Table 23. Repair Parts Cost

[Baseline year - 1983]

Item	50-tpd HRI ($)	100-tpd HRI[a] ($)	150-tpd HRI[b] ($)
Scale	300	300	300
Crane	300	300	300
Incinerator	2,000	4,000	5,100
Boiler	1,000	2,000	2,550
Water Treatment	300	600	765
Electrical	3,000	6,000	7,650
ESP	1,500	3,000	3,825
Miscellaneous	2,600	5,200	6,630
Total	11,000	21,400	27,120

[a]Cost = 2 x 50-tpd cost.

[b]Cost (50-tpd) x $1.5^{0.6}$ x 2 units. 1.5 = 75/50 which is parts cost increase for a 75-tpd unit.

Table 24. Equipment Replacement Cost[a]

[Baseline year - 1983]

Item	50-tpd HRI ($)	100-tpd HRI ($)	150-tpd HRI ($)
Feed Hopper	10,200	24,555	31,320
Crane	10,130	15,355	19,585
Boiler	28,350	42,970	54,805
Residue Removal	40,500	61,385	78,295
Grate	20,250	30,695	39,145
Air Compressor	10,130	15,355	19,585
Refractory	19,440	29,465	37,580
Boiler Feedwater	810	1,230	1,565
ESP	81,000	122,775	156,590
Instrumentation (5)	16,300	24,705	31,510
(10)	10,130	15,355	19,585
Building[b] (5)	16,300	21,505	25,295
(10)	20,250	26,720	31,425
Boiler (5)	2,610	3,955	5,045
(10)	1,620	2,455	3,130
I.D. Fan	3,240	4,910	6,265
Total	297,260	443,390	560,725

[a] Cost at 50 tpd x (no. of units)$^{0.6}$

[b] Cost at 50 tpd x (no. of units)$^{0.4}$

Table 25. 50-tpd Life-Cycle Economics

[Baseline year - 1983]

Item	Costs	Amount	Discount Factor	Estimate
1.	Capital	$2,859,000	x 1	$2,859,000
2.	O&M	$344,200	7.98	$2,746,716
3.	Replacement	$297,260	1	$297,260
4.	Total Life Cycle (1 + 2 + 3)	---	---	$5,901,976
5.	Life Cycle Steam Production[a]	$67{,}500 \times 10^6$ x 15 yr	7.98	$1{,}012{,}500 \times 10^6$ Btu
6.	Life Cycle Steam Production (4 ÷ 5)	---	---	$\$5.83/10^6$
7.	Life Cycle Steam[b]	$662,850	7.98	$5,289,543
8.	Net Life Cycle Disposal (4 - 7)	---	---	$612,433
9.	Net Life Cycle Disposal Tonnage[c]	168,750	---	---
10.	Life Cycle Disposal (8 ÷ 9)	---	---	$3.63/ton

[a] 5,000 Btu/lb x 2,000 lb/ton x 0.60 x tons solid waste/year.

[b] Item 5 x $1.10/gal/112,016 Btu/gal.

[c] 45 weeks x 5 days/week x HRI tpd x 15 years.

Table 26. 100-tpd HRI Life-Cycle Economics

[Baseline year - 1983]

Item	Costs	Amount	Discount Factor	Estimate
1.	Capital	$4,143,850	1	$4,143,850
2.	O&M	$486,560	7.98	$3,882,750
3.	Replacement	$443,390	---	$443,390
4.	Total Life Cycle (1 + 2 + 3)	---	---	$8,469,990
5.	Life Cycle Steam Production[a]	135,000 x 10^6 Btu x 15 yr	---	2,025,000 x 10^6 Btu
6.	Life Cycle Steam Production (4 ÷ 5)	---	---	$4.18/$10^6$ Btu
7.	Life Cycle Steam[b]	$1,325,700	7.98	$10,579,115
8.	Net Life Cycle Disposal (4 - 7)	---	---	(-) $2,109,125
9.	Net Life Cycle Disposal Tonnage[c]	337,500 tons	---	---
10.	Life Cycle Disposal (8 ÷ 9)	---	---	(-) $6.25/ton (savings)

[a]5,000 Btu/lb x 2,000 lb/ton x 0.60 x tons solid waste/year

[b]Item 5 x $1.10/gal/112,016 Btu/gal

[c]45 weeks x 5 days/week x HRI tpd x 15 years

Table 27. 150-tpd HRI Life-Cycle Economics

[Baseline year - 1983]

Item	Costs	Amount	Discount Factor	Estimate
1.	Capital	$5,164,645	1	$5,164,645
2.	O&M	$600,320	7.98	$4,790,555
3.	Replacement	$560,725	---	$560,725
4.	Total Life Cycle (1 + 2 + 3)	---	---	$10,515,925
5.	Life Cycle Steam Production[a]	202,500 x 10^6 Btu x 15 yr	---	3,037,500 x 10^6 Btu
6.	Life Cycle Steam Production (4 ÷ 5)	---	---	$3.46/$10^6$ Btu
7.	Life Cycle Steam[b]	$1,988,555	7.98	$15,868,670
8.	Net Life Cycle Disposal (4 - 7)	---	---	(-) $5,352,745
9.	Net Life Cycle Disposal Tonnage[c]	506,250 tons	---	---
10.	Life Cycle Disposal (8 ÷ 9)	---	---	(-) $10.57/ton (savings)

[a]5,000 Btu/lb x 2,000 lb/ton x 0.60 x tons solid waste/year

[b]Item 5 x $1.10/gal/112,016 Btu/gal

[c]45 weeks x 5 days/week x HRI tpd x 15 years

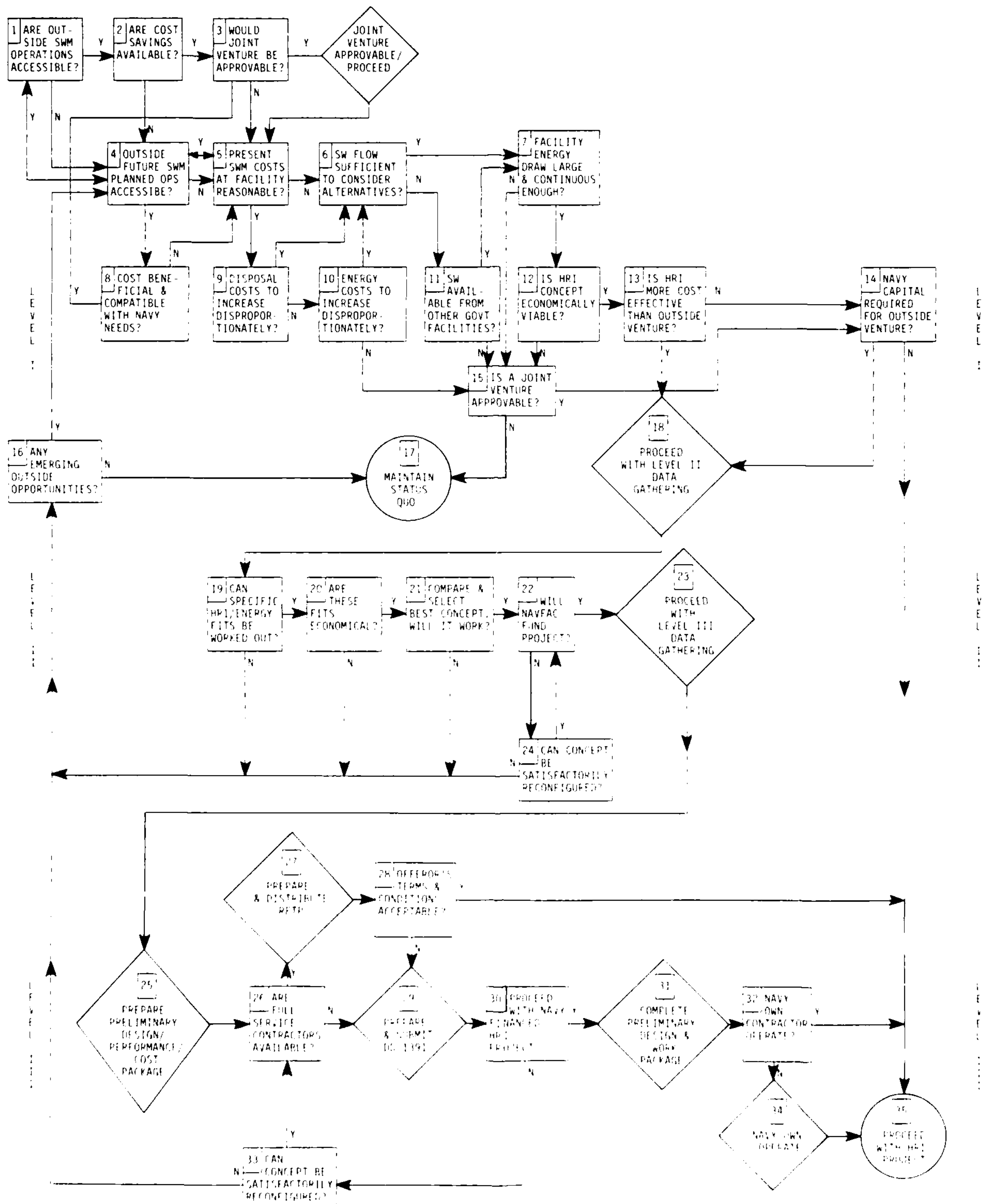

Figure 1. HRI decision diagram.

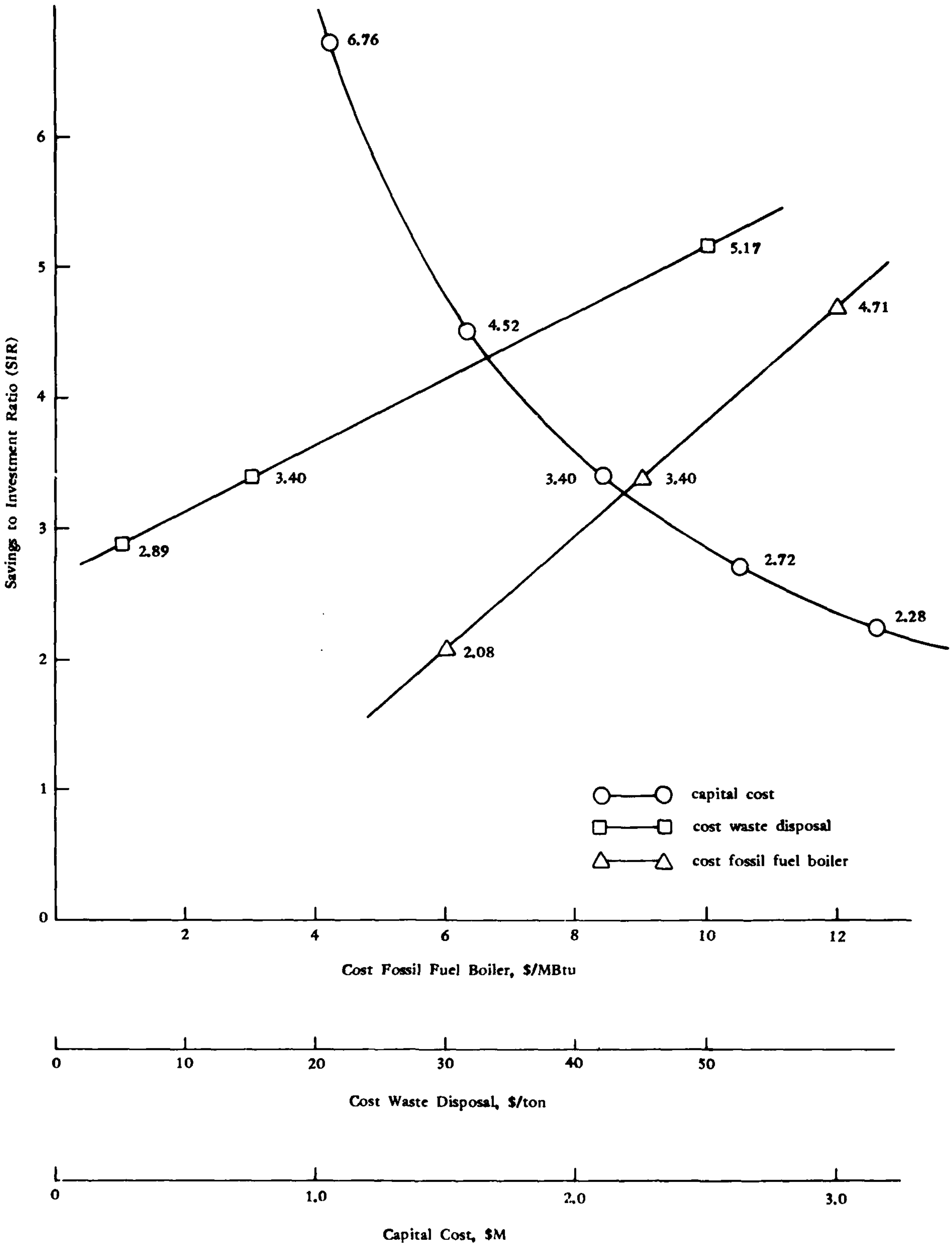

Figure 2. Savings to investment ratio versus boiler, disposal and capital costs.

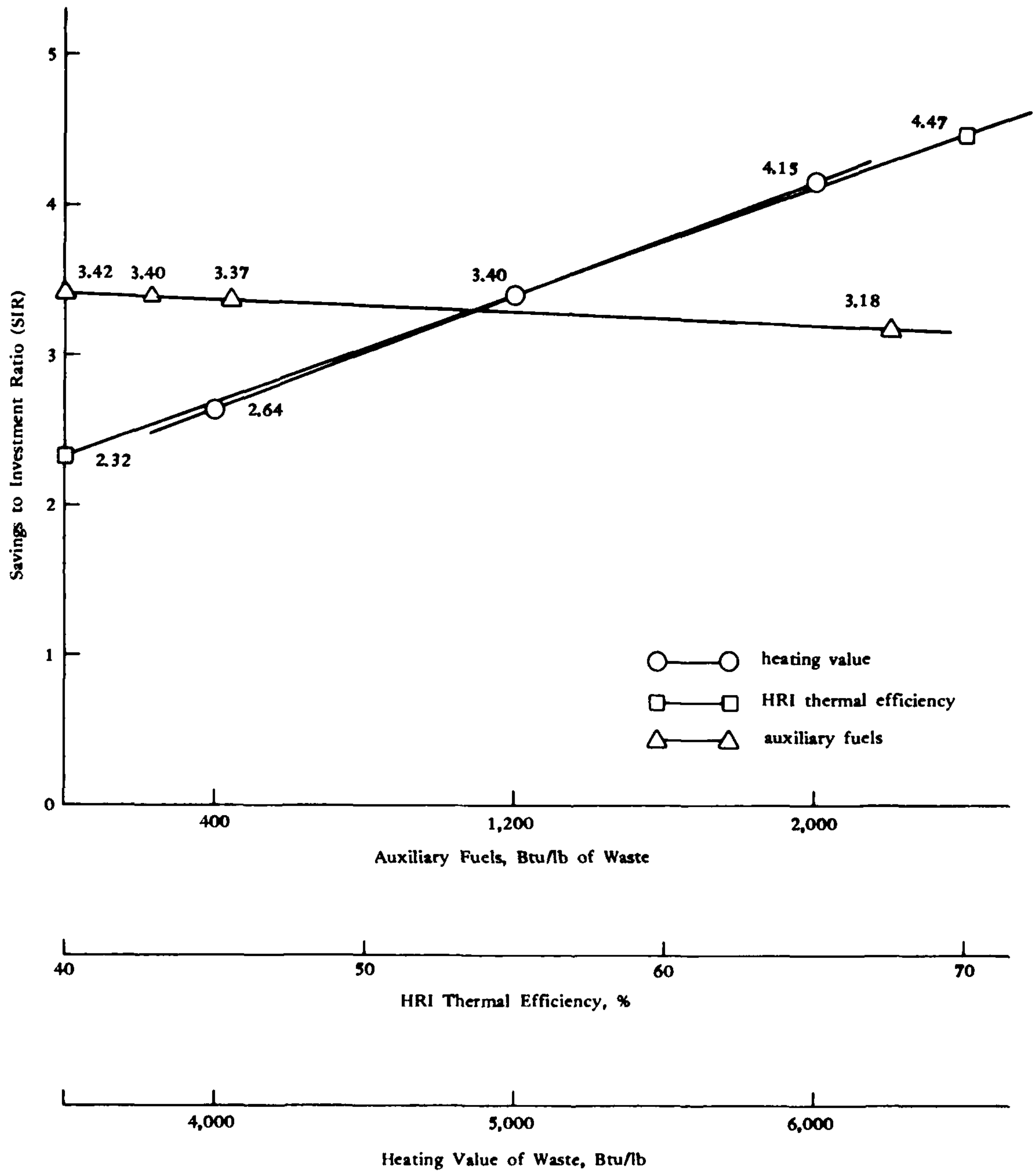

Figure 3. Savings to investment ratio versus auxiliary fuels, thermal efficiency, and heating value of SW.

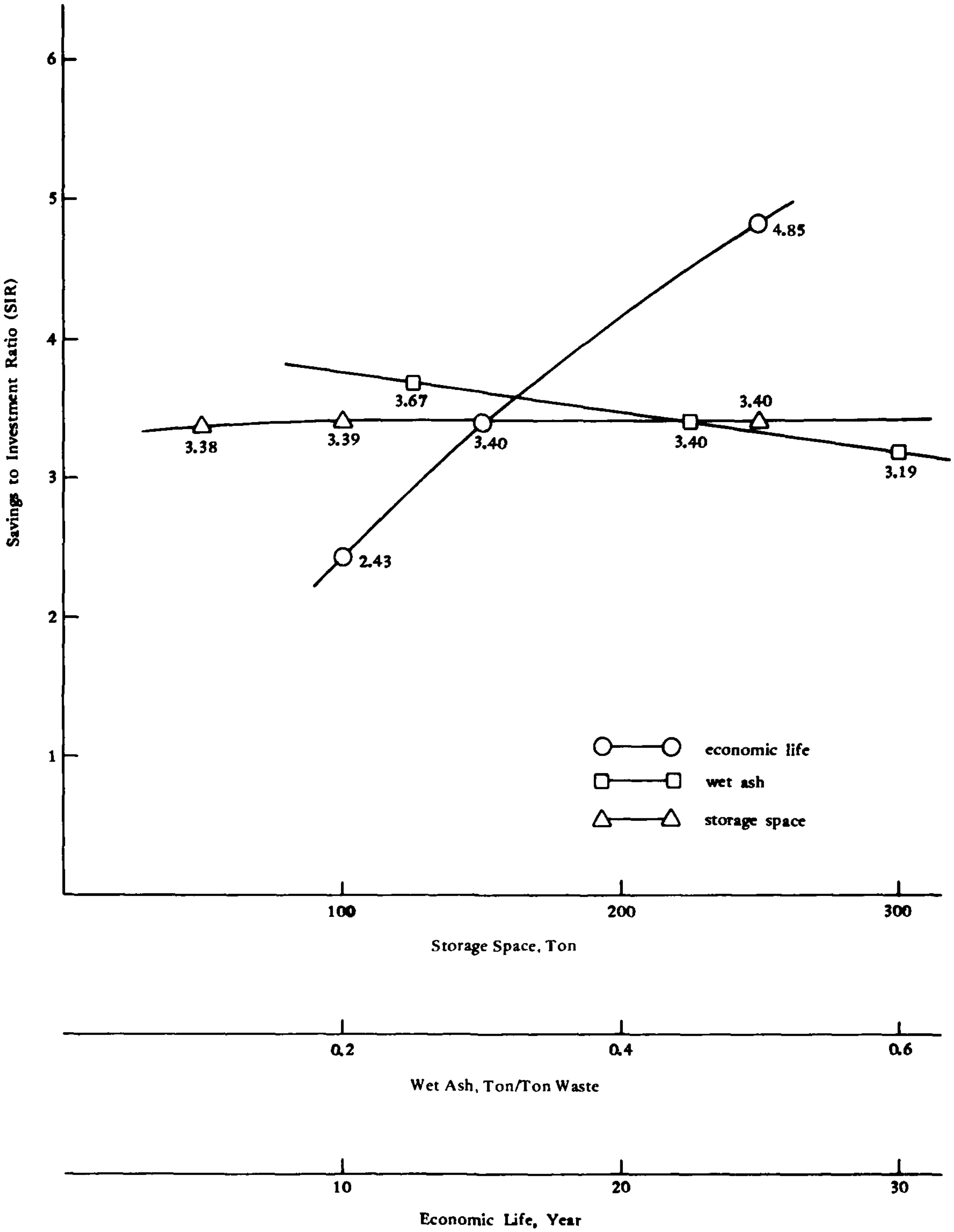

Figure 4. Savings to investment ratio versus storage space, residue wet ash, and economic life.

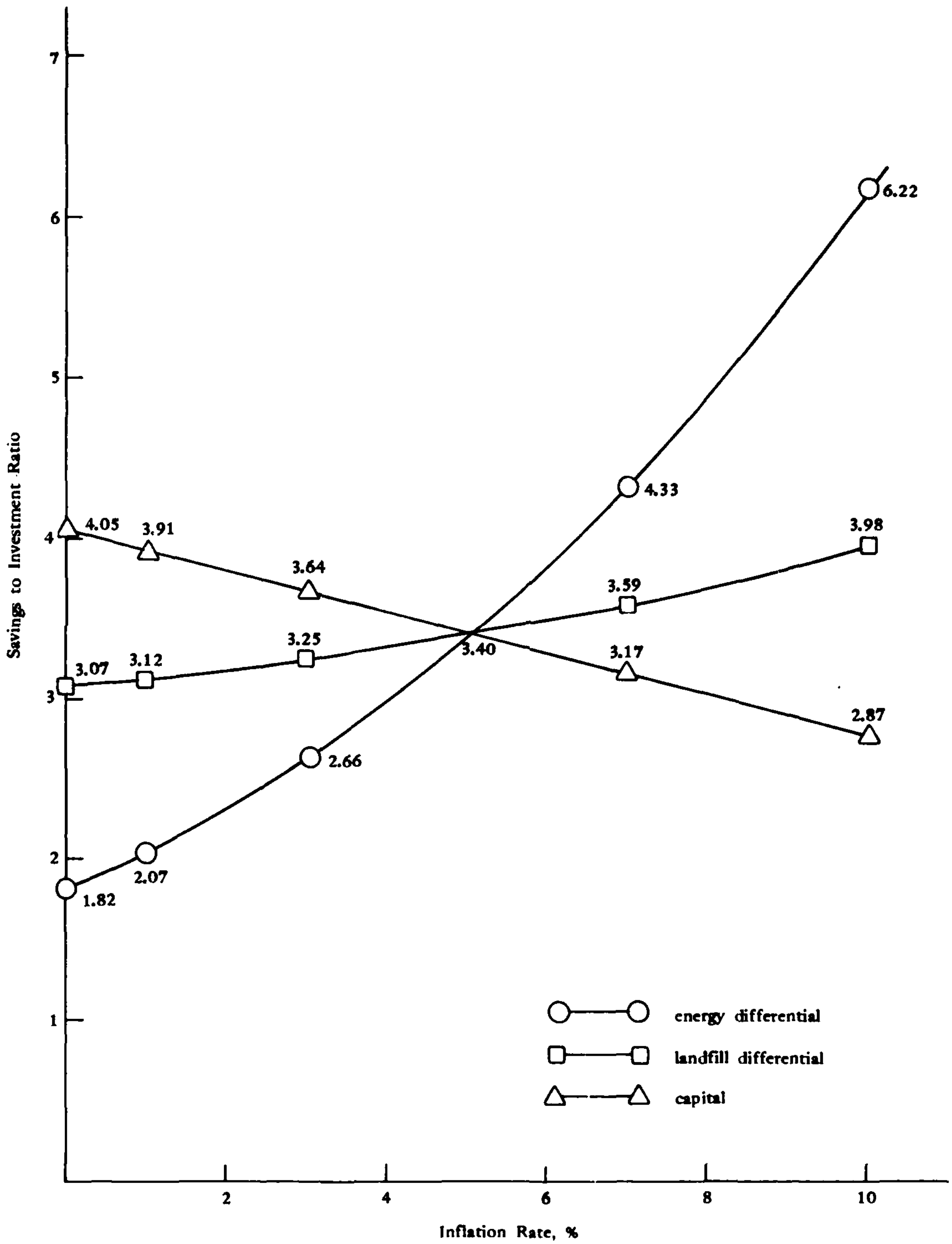

Figure 5. Savings to investment ratio versus inflation rate.

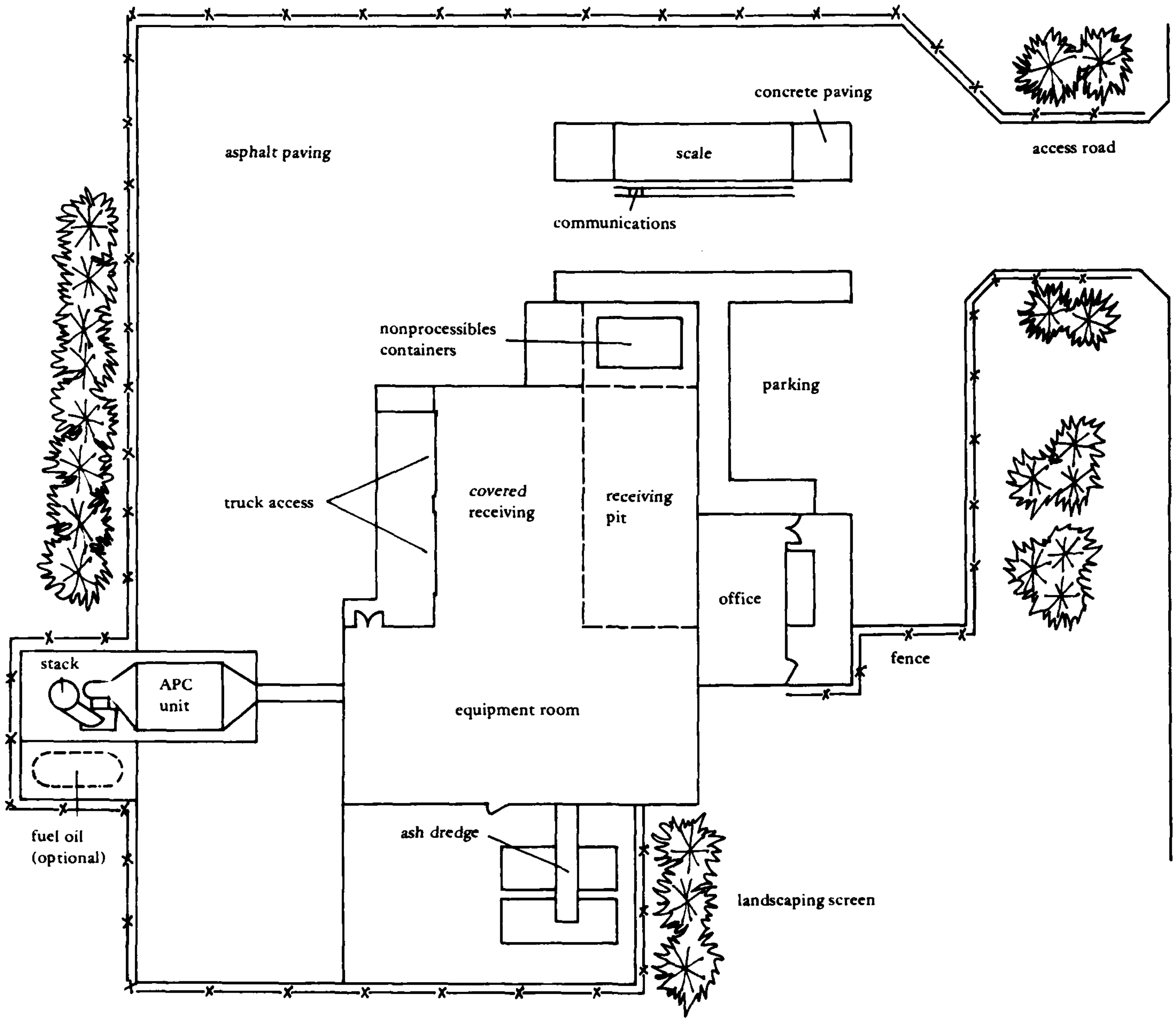

Figure 6. Conceptual site layout for NAVFAC optimum HRI plant.

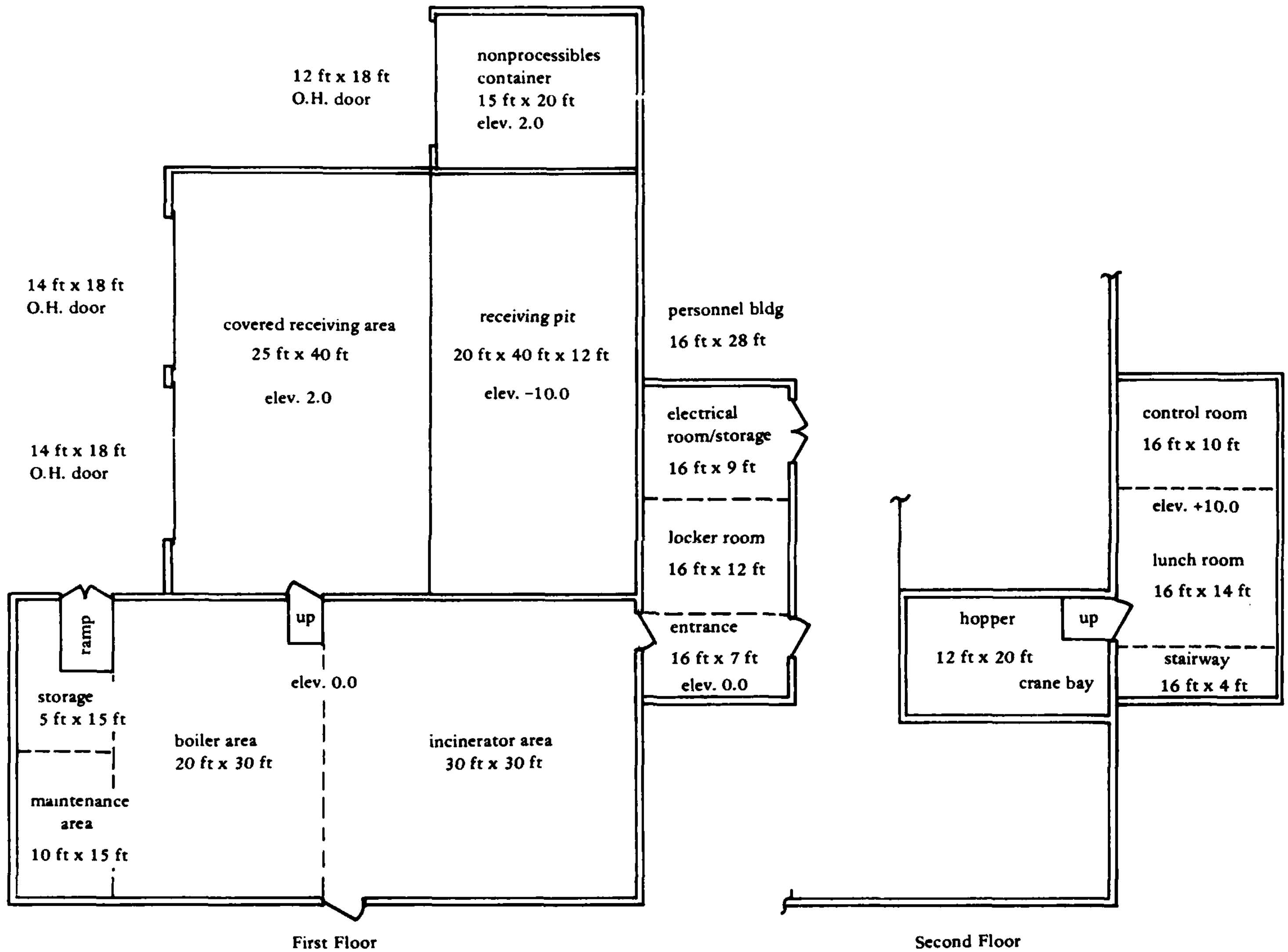

Figure 7. Conceptual plan arrangement for NAVFAC optimum HRI building.

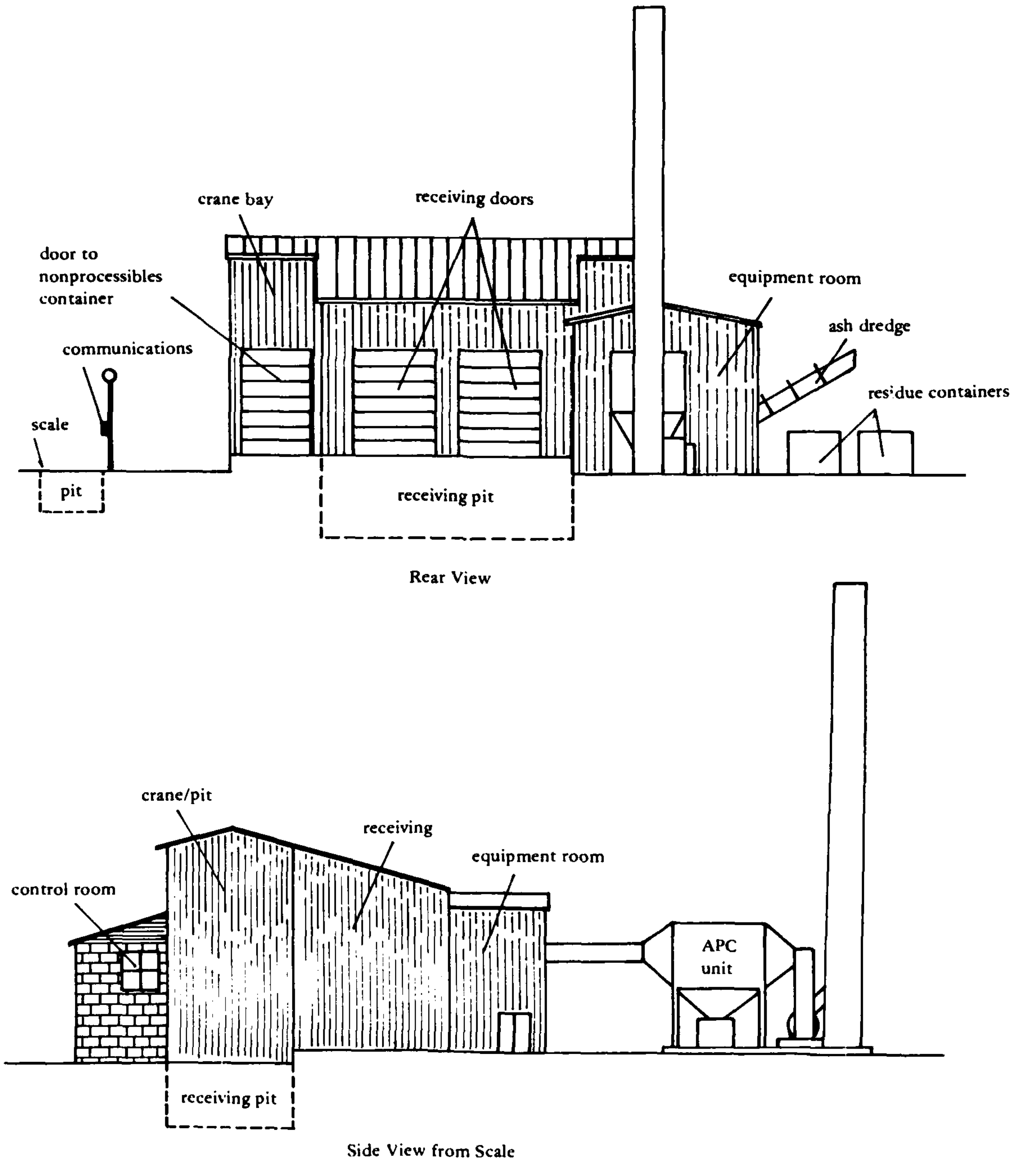

Figure 8. Elevations of conceptual HRI building for NAVFAC optimum HRI plant.

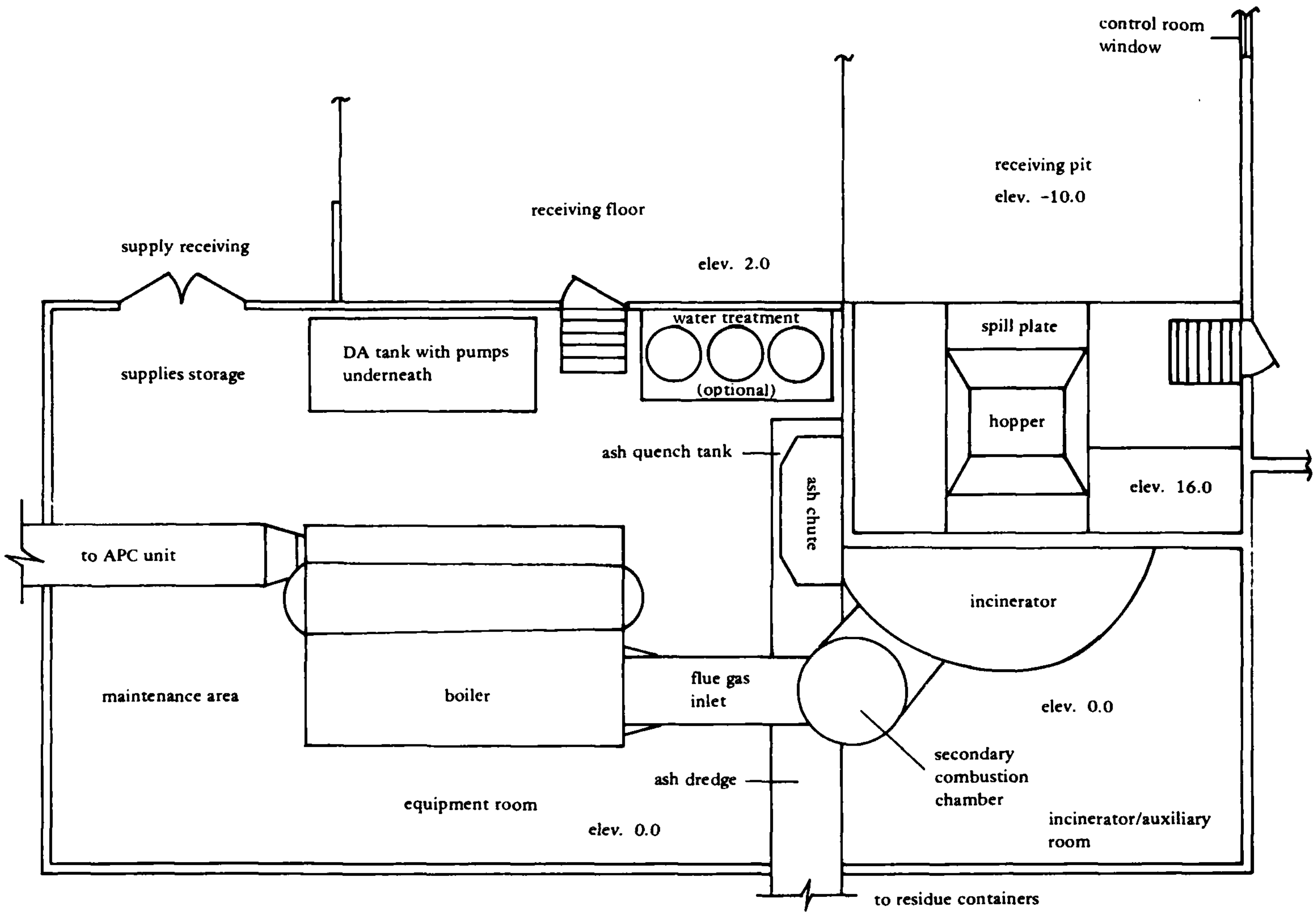

Figure 9. Conceptual layout of boiler room of NAVFAC optimum HRI plant.

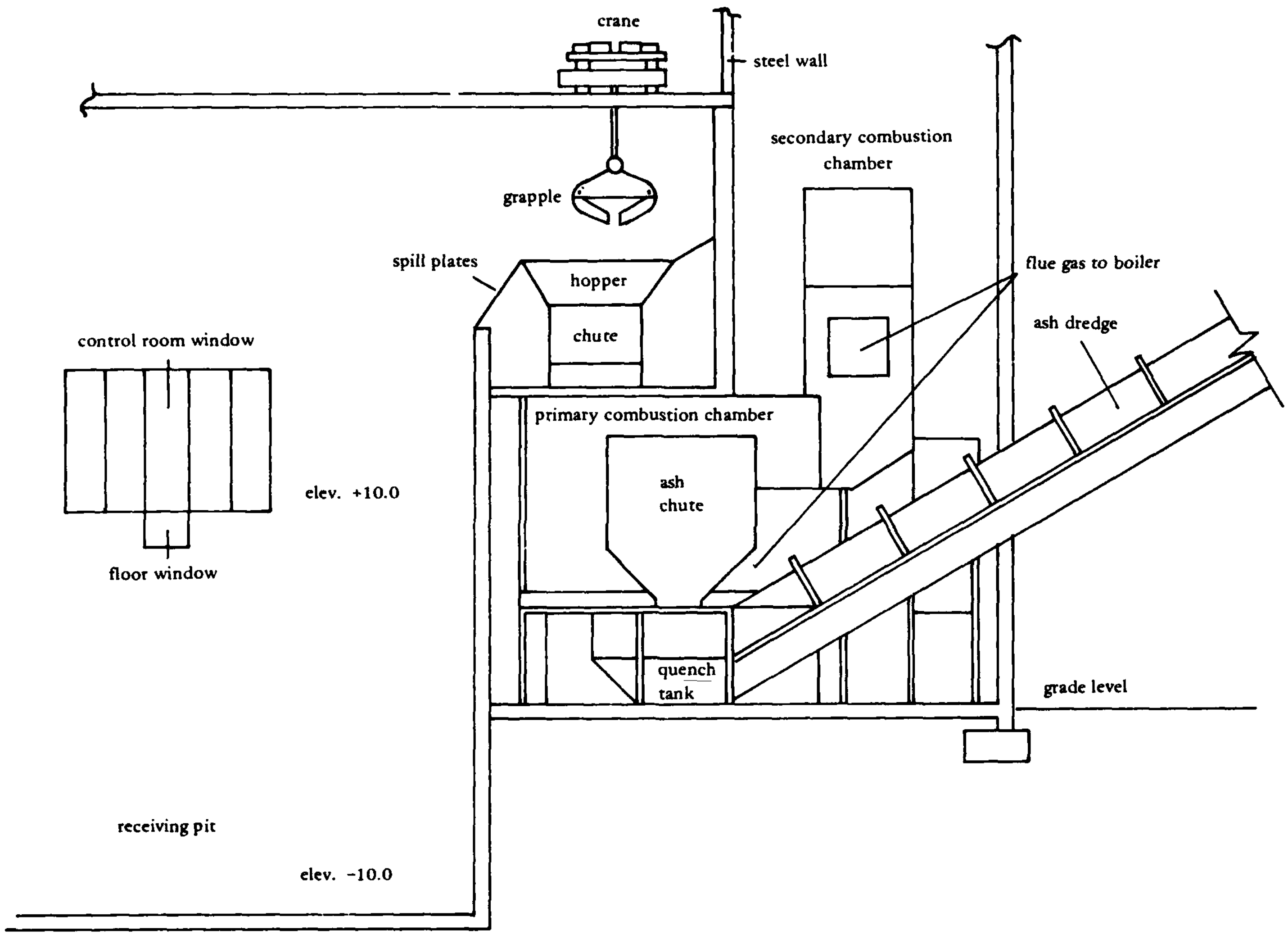

Figure 10. Conceptual elevation view of boiler room of NAVFAC optimum HRI plant.

Appendix A

WORKSHEETS

WORKSHEET 1

SOLID WASTE DISPOSAL COST WORKSHEET. Complete this worksheet to determine current solid waste collection and disposal costs.

Disposal costs are defined as the expenses involved in removing the waste from the activity to a disposal site (landfill, transfer station, etc.). The expenses of disposal are categorized in three areas: Labor, equipment, and materials.

If the waste is collected by a private company, the contract cost can be broken down into collection and disposal costs depending on local disposal fees, labor rates, and distance to the disposal site. Estimated values are 60% for collection and 40% for disposal. This also applies if a single account is used to charge collection and disposal costs or where the same trucks are used for collection and disposal.

Table WS 1-1. Disposal Expenses

On-Base Navy Operated Landfill

Labor							
Landfill equipment Operators	____	[hrs/yr]*	____	[$/hr][a]	=	____	[$/yr]
Truck operators	____	*	____		=	____	
Supervisors	____	*	____		=	____	
Mechanics	____	*	____		=	____	
Additional personnel	____	*	____		=	____	
Equipment							
Equipment costs	____	[$] ÷	____	[Equipment Life, yrs]	=	____	[$/yr]
Facilities costs	____	÷	____		=	____	
Materials							
Fuel	____	[gal/yr]*	____	[$/gal]	=	____	[$/yr]
Cover dirt*	____	[yd^3/yr]*	____	[$/$yd^3$]	=	____	
Parts, oil, etc.						____	

TOTAL DISPOSAL COST ____ [$/yr]

OR if a single account is used for Collection and Disposal,
Disposal Cost = ____ [total account cost/year] * 0.40

= ____ [$/yr]

[a]Labor rates used must include overhead changes and benefits.

WORKSHEET 2

BASE ENERGY DEMAND. This worksheet is intended to provide an estimate of the energy demand on base and a breakdown of the demand into various energy types (electricity, steam, hot water, etc.).

Table WS 2-1 should be completed as follows:

1. The type of system should be listed as superheated steam (SH) saturated steam (SS), or hot water (HW).

2. Report the average daily energy demand* by season, defined as follows:

Season	Months
Spring	March-May
Summer	June-August
Fall	September-November
Winter	December-February

*Divide each average daily energy demand by the boilers thermal efficiency. Use 0.8 if the efficiency is unknown.

Table WS 2-1. Energy Demand Survey

Location ____________________ Date ____________________

Steam or Hot Water Loops

Loop Number	Location	Type of System	Operating Pressure (psi)	Normal Fuel Type	Units	Average Daily Energy Demand			
						Spring	Summer	Fall	Winter

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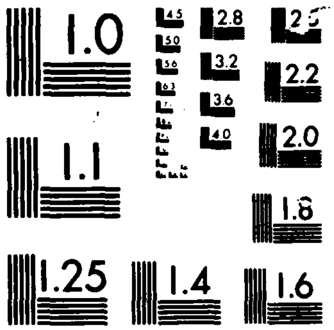


MICROCOP CHART

WORKSHEET 3

PRELIMINARY COSTS AND BENEFITS OF AN HRI. This worksheet is designed to allow a preliminary cost-benefit analysis of an HRI plant to be conducted. The quantity of solid waste available, in tons per day (TPD), will be used throughout this worksheet to calculate the first level savings and benefits. The TPD value was determined in Section 2, Decision Step 6, of this chapter.

PROJECTED CAPITAL COSTS. The size of an HRI facility may be approximated from the daily SW tonnage. Although HRI plants would actually be built in various incremental sizes, for this preliminary analysis, a unit facility cost can be obtained by using the nearest incremental TPD unit cost listed in Table WS 3-1.

Table WS 3-1. Approximate Cost per Ton of Daily Capacity of HRI Facility (Ref 5)

Size (TPD)	HRI Facility Cost (1983 dollars x 10^3)
12.5	1,200
25.0	1,700
50.0	2,800
100.0	4,800
150.0	6,450
200.0	7,600

The plant costs per daily tonnage in the above table include the cost of site work, building, equipment, and installation. Use the following table to estimate air pollution control (APC) equipment cost. This table has been separated out from WS 3-1 since some types of HRI's in certain jurisdictions will not require APC equipment. Consult your EFD environmental affairs officer in this regard.

Table WS 3-2. Approximate Cost of Air Pollution Control (APC) Equipment per Ton of Daily Capacity (Ref 5)

Facility Size (TPD)	APC Cost (1983 $)
12.5	150,000
25.0	175,000
50.0	225,000
100.0	300,000
150.0	included in base cost
200.0	included in base cost

Complete the following table to estimate the total plant cost:

Table WS 3-3. Projected Capital Cost of HRI

	Estimated Cost
HRI facility (from Table WS 3-1)	____________
Additional site preparation	____________
Demolition	____________
Drainage	____________
Roadway	____________
Air pollution control (from Table WS 3-2)	____________
TOTAL	____________

PROJECTED LABOR COSTS. The number of personnel required for a specific size plant may be estimated *from Table* WS 3-4. One should research local hourly rates for personnel to accurately predict the total personnel costs on Table WS 3-5. These tabulations are based on an operational scenario of continuous firing, 5 days per week. This arrangement is considered optimum for the average sized HRI (about 50 tpd) required for the typical Navy activity. Unlike larger waste-fired steam generators (water-walled) which can operate over extended periods, the 50 tpd class HRI should be shut down weekly to clean the furnace which will usually be refractory not water-wall. The reader may, however, consider other manning arrangements for other operating scenarios by consulting Reference (5).

Labor rates must include burden as well the hourly wage. Because most overhead items are separately included in these worksheets, burden should only include acceleration and fringe benefits. For that purpose it is suggested that 40% be added to the hourly wage.

Table WS 3-4. Labor Recommended for Operation of HRI Facility, 5 days/wk, 24 hrs/day Versus Size of Facility (Ref 5)

Position	WG Rating	HRI Size, tons/day					
		12-25	50	100	150	200	250
Foreman	10	1	1	1	1	2	2
Operator	10	2	3	3	3	3	3
Assistant Operator	8	3	4	4	4	4	4
Mechanic	10	1	1	1	1	2	2
Electrician	10	0	0	1	1	1	1
Laborer	6	0	0	1	2	3	3
TOTAL		7	9	11	12	15	15

Table WS 3-5. Personnel Requirements for Operation and Maintenance of an HRI Facility, 5 days/wk, 24 hrs/day (Ref 5)

Position	No.	Annual Man-hours	Local Rate/hr	Projected Annual Total Costs [$/yr]
Supervisor	1	520	______	______
Accountant	1	520	______	______
Foreman	___	2,080	______	______
Operators	___	2,080	______	______
Assistant Operators	___	2,080	______	______
Mechanic	___	2,080	______	______
Electrician	___	2,080	______	______
Laborer	___	2,080	______	______
TOTAL			______	______

PROJECTED ENERGY OPERATION COSTS. To estimate the annual energy required for the operation of an HRI Plant, complete this next table (WS 3-6).

Table WS 3-6. Projected Annual Energy Consumption by Equipment in HRI Facility Operating 5 days/wk, 24 hrs/day (Ref 5)

Item	TPD		Days Year							$/yr
Electricity	_____	*	260	*	50.0 (kW-hr/ton)	*	_____	($/kW-hr)	=	_____
Auxiliary Fuel	_____	*	260	*	0.03 (MBtu/ton)	*	_____	($/MBtu)	=	_____

PROJECTED NONENERGY COSTS. Nonenergy costs in the operation of an HRI plant (nonprocessed disposal and maintenance) may be estimated from the next table (WS 3-7). If local costs are not available for residue and nonprocessed disposal, use an average value of $12.25/ton and $33/ton (1983 $) respectively, in the preliminary study.

Table WS 3-7. Projected Annual Cost for Nonenergy Items of the HRI Facility Operating 5 days/wk, 24 hrs/day (Ref 5)

Item	Unit Cost ($)		Units/ton		TPD		$/yr
Residue disposal	_____/ton	*	117	*	_____	*	_____
Nonprocessible disposal	_____/ton	*	6.5	*	_____	*	_____
Maintenance	5	*	260	*	_____	*	_____
TOTAL							_____

PROJECTED DAILY TONNAGE UTILIZED. The quantity of solid waste available for incineration varies considerably from the incoming tonnage after the removal of nonprocessible materials. Reduce the incoming TPD value by 10% to account for the removal of nonprocessibles.

PROJECTED BENEFITS. The amount of energy produced per year from an HRI may be approximated in the following equation:

$$\text{Energy Displaced} = 5.0\ (\text{MBtu/TPD}) * \_\_\_\_\_\ (\text{TPD}) * 260\ (\text{Days/yr}) \quad (\text{Eq WS 3-1})$$

$$= \_\_\_\_\_\ (\text{MBtu/yr})$$

The energy factors used in Equation WS 3-1 include the plant's overall thermal efficiency (conservatively, 50%) and average waste energy content of solid waste. Use this calculated value of energy displaced per year (from Equation WS 3-1) to estimate the dollars saved per year (for the appropriate fuel currently used) in Table WS 3-8.

Table WS 3-8. Energy Type and Annual Cost

Energy Type	Units per MBtu		Unit Cost ($/unit)		Energy Displaced (MBtu/yr)		Fuel Saved ($/yr)
Distillate fuel oil	7.2 gal	*	_____	*	_____	=	_____
Residual fuel oil	6.7 gal	*	_____	*	_____	=	_____
Natural gas	0.97 kft^3	*	_____	*	_____	=	_____
LPG, propane, butane	10.5 gal	*	_____	*	_____	=	_____
Bituminous coal	0.04 ton	*	_____	*	_____	=	_____
Anthracite coal	0.04 ton	*	_____	*	_____	=	_____
Purchased steam	746 lb	*	_____	*	_____	=	_____

The money saved in disposal costs is also considered a benefit of the HRI. Disposal costs were estimated in Worksheet 1; use that value in the economic analysis of an HRI, Table WS 3-9.

Table WS 3-9. Economic Analysis of an HRI

	Amount		Discount Factor[a]		Estimate ($/yr)
1. Capital Costs (Table WS 3-3)					______
2. Operation Costs					
Personnel (Table WS 3-5)	______				
Operation Energy Costs (Table WS 3-6)	______				
Non-Energy Costs (Table WS 3-7)	______				
TOTAL	______	[$/yr]*	______	=	______
3. Energy Credit (fuel saved) (Table WS 3-8)	______	[$/yr]*	______	=	______
4. Disposal Credit (Worksheet 1)	______	[$/yr]*	______	=	______

5. If (3 + 4)/(1 + 2) <1 then project does not qualify.

[a]The discount factor is based on the life of the facility and the relative escalation rate of the associated costs. Therefore, this factor can be varied if one (or more) of the annual expenses is expected to escalate at a faster rate than the others. For example, the discount factor (assuming an HRI plant lift of 15 years and energy prices to rise at a 6% faster rate than Operation Costs and Disposal Costs) for Energy Credit would be 11.508 as compared to 7.980 for Operation Costs and Disposal Costs. This factor can be obtained from NAVFAC P442.

Worksheet 4. HRI/Energy Fits

A survey of the various energy draw points on base was completed in Table WS 2-1. The total energy drawn at the activity can be compared with the HRIs rated outputs from Equation WS 3-1. On Table WS 4-1, compare the HRI's rated output with the energy loops identified in Table WS 2-1 that would be compatible with the steam conditions provided by the HRI (see "HEAT RECOVERY SYSTEM").

The factors that should be considered when selecting a loop to utilize the energy from a HRI include:

(a) Fuel Type -- Replace the most expensive fuels (oil, gas, etc.).

(b) Energy Type -- The often preferred use of hot water and low pressure steam to provide the energy over high pressure steam and electricity.

(c) Energy Demand -- Energy demand that is always greater than the HRI output is preferred.

(d) Location -- Proximity of HRI and the energy consuming points. Siting in accordance with the approved activity Master Plan.

Table WS 4-1. Comparison of HRIs Rated Output to Energy Demand on Various Loops

	Energy Demand [MBtu/season]				Total [MBtu/yr]	Individual Loops, %
	Winter	Spring	Summer	Fall		
HRI Rated Output (Equation WS 3-1)					______	
Loop Energy Demand (Table WS 2-7)						
# ______	______	______	______	______	______	______
# ______	______	______	______	______	______	______
# ______	______	______	______	______	______	______
# ______	______	______	______	______	______	______
# ______	______	______	______	______	______	______
# ______	______	______	______	______	______	______

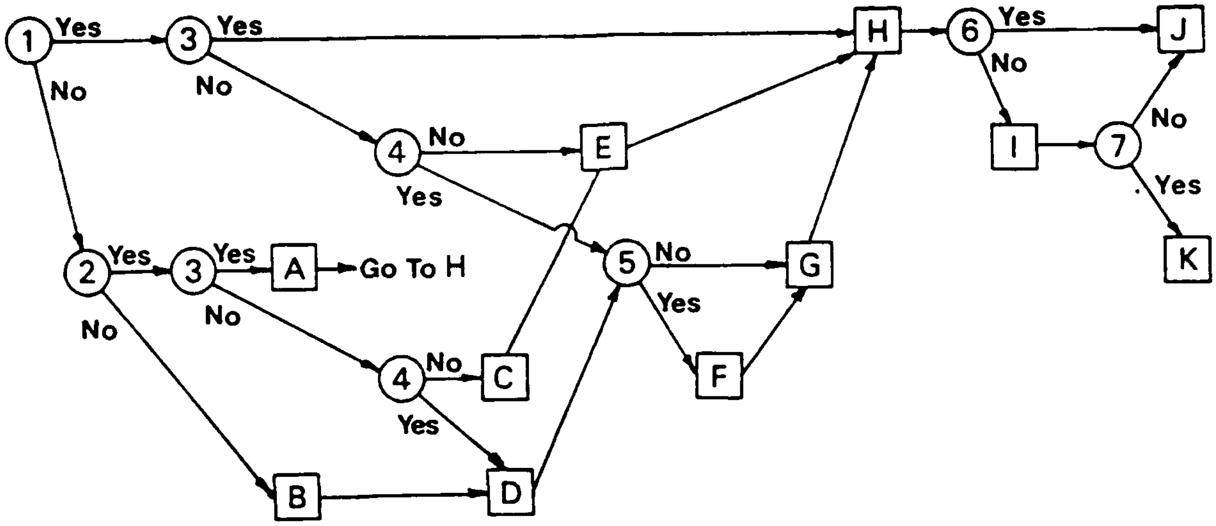
Appendix B

INSTRUCTIONS FOR CONDUCTING A WASTE SURVEY

Figure B-1 is a logic chart for conducting a waste survey. The circled numbers are questions that, when answered, lead the preparer to different actions (boxed letters) that must be taken. To complete the survey, begin at Question 1 and follow the appropriate paths to the right of the chart to one of the two waste survey completion points, J or K. Perform only those actions called for in the path you are following. All the questions are self explanatory except for questions about waste categories which are explained in the next paragraph.

Three categories of waste are used for the survey. The first category is commercial wastes (predominately paper, cardboard, wood) that emanate from activities such as offices, warehouses, exchanges, industrial activities, etc. The second category is residential (wastes that contains significant quantities of food waste, glass, cans, clothing) and is associated with family housing, barracks, the commissary, etc. The third category of waste is debris (brush, tree branches, demolition, etc.) that originates from cleanup and construction activities. The debris wastes will not be included as potential fuels for an HRI facility. Therefore, the percentage of debris calculated needs to be considered only if included in the waste generation data totals.

The following are detailed instructions for completing each of the action items identified in the waste survey logic chart. If the final instructions for any action do not indicate that you should go to another action, refer to the logic chart to determine the next question.



QUESTIONS

1. Are waste disposal weight records available?
2. Are waste disposal volume records available?
3. Are the records differentiated into waste categories?
4. Are the records for each waste truck available?
5. Does any truck collect two categories of wastes?
6. Does the activity waste generation rate average more than 200 TPD_5?
7. Does the activity commercial waste generation rate average less than 12.5 TPD_5, and does the sum of the on-base commercial and residential waste generation rate and off-base alternative fuels average less than 25 TPD_5.

ACTIONS

A. Convert volume records to weight data by categories.
B. Estimate waste generation (volume).
C. Convert volume records to weight data by totals.
D. Convert volume data to weight data by truck.
E. Estimate waste category distribution for all wastes.
F. Estimate waste category distribution by truck.
G. Estimate waste generation (weight) by category.
H. Estimate average daily generation rate.
I. Define the auxiliary fuels available.
J. Begin the energy survey.
K. Stop work on the feasibility study.

Figure B-1. Waste survey logic chart.

Action A - Convert Volume Records to Weight Data by Categories

Using the waste disposal volume records from the previous year, complete Table A as follows.

1. Separately calculate the total disposal rates by volume for the commercial wastes and the sum of the commercial and residential wastes for each season. Record these rates on the first line of Table A.

2. Estimate the density of the waste at the point where volumes were measured for each category using your own density values of the appropriate values as follows:

Type of Truck	Density (tons/yd^3)
Front loader (F)	0.20
Rear loader (R)	0.30
Roll-off (noncompacted) (O)	0.06

3. If more than one type of truck was used during collection, calculate a "proportional average" density for that category.

4. Multiply the volume rate by the appropriate density value and record the estimated waste generation rate by weight on the bottom line of Table A. Go to Action H.

TABLE A. VOLUME RECORDS CONVERSION TO WEIGHT ESTIMATES BY CATEGORY

	Winter		Spring		Summer		Fall	
	C*	C+R†	C	C+R	C	C+R	C	C+R
Volume (yd^3)	___	___	___	___	___	___	___	___
Density (tons/yd^3)	___	___	___	___	___	___	___	___
Weight (tons)	___	___	___	___	___	___	___	___

* C = Commercial

† C+R = Commercial and residential

Action B - Estimate Waste Generation (Volume)

Using Table B, perform the following tasks:

1. Record the truck numbers for all trucks that haul residential and commercial refuse in Column 1.

2. Write the typical refuse volume payload of each truck into Column 2 by multiplying the volume capacity of the truck by the typical percentage of total volume filled. If the percentage of total volume filled is not known, assume 95 percent.

3. Estimate the number of trips per week that each truck makes to the landfill. Multiply the number of trips per week by 13 for each season, and record the product in Column 3.

4. Multiply the truck volume of each truck by the landfill trips per season to obtain the volume per season, and record this value in Column 4 for each season.

5. Go to Action D.

TABLE B. ESTIMATING WASTE GENERATION (VOLUME)

(1) Truck no.	(2) Truck volume (cy)	(3) Landfill trips per season				(4) Total volume per season			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall

Action C - Convert Volume Records to Weight Data by Totals

Using the waste disposal volume records from the previous year, complete Table C as follows:

1. Calculate the total waste disposal rates by volume for each season and record these values on the top line on Table C.

2. Record the estimated density of the waste on the next line of Table C using procedures presented in Step 2 of Action A.

3. Multiply the seasonal volumes by the density value and record the product on the bottom line of Table C.

4. Go to Action E.

TABLE C. VOLUME RECORDS CONVERSION TO TOTAL WEIGHT ESTIMATES

	Winter	Spring	Summer	Fall
Volume (yd^3)	________	________	________	________
Density ($tons/yd^3$)	________	________	________	________
Weight (tons)	________	________	________	________

Action D - Convert Volume Data to Weight Data by Truck

Complete Table D as follows:

1. Enter the truck number and truck type (front loader [F], rear loader [R], and roll-off [O]) for each refuse truck hauling commercial or residential waste.

2. Using the waste disposal volume records or the volume data in Column 4, Table B, calculate the average seasonal waste disposal volumes for each truck and record these values in Column 2.

3. Record the estimated density of the waste in each truck in Column 3, using your density estimate or the values presented in Action A.

4. For each truck, multiply the seasonal volume in Column 2 by that truck's density factor in Column 3. Record these products in Column 4.

TABLE D. VOLUME RECORDS CONVERSION TO WEIGHT ESTIMATES BY TRUCK

(1) Truck no./type	(2) Total volume per season				(3) Density (ton/yd^3)	(4) Total weight per season			
	Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall

Action E - Estimate the Waste Distribution by Category for all Wastes

Table E should be completed as follows:

1. Obtain the seasonal waste generation rates from the waste disposal weight records or from the bottom line of Table C and record these values on the first line of Table E.

2. Using your knowledge or information you obtain, estimate (based upon waste truck traffic schedules or other personal knowledge) the category distribution for each season as a percentage of the total waste and record these values on the third line in Table E. The tree waste categories are debris, commercial, and residential.

3. Multiply the total tons per season by the distribution percentage for each category to calculate the waste generation rate by weight for each season and waste category.

4. Record these values on the bottom line of Table E.

5. Go to Action H.

TABLE E. ESTIMATE WASTE CATEGORY DISTRIBUTION FOR ALL WASTES

	Winter			Spring			Summer			Fall		
Total (tons)	___			___			___			___		
Category	D*	C†	R§	D	C	R	D	C	R	D	C	R
Distribution (%)	___	___	___	___	___	___	___	___	___	___	___	___
Distribution (ton)	___	___	___	___	___	___	___	___	___	___	___	___

* D = Debris
† C = Commercial
§ R = Residential

Action F - Estimate Waste Category Distribution by Truck

Table F should be completed as follows for each truck that is used to pick up more than one category of waste during the year.

1. Write the truck number on line A.

2. Identify each container that the truck typically collects by a number or location in Column 1.

3. Identify the typical volume of refuse in each container, and write this volume (cubic yards) in Column 2.

4. Estimate the number of times per week that the truck picks up this container. Enter this number in Column 3.

5. Calculate the volume collected per week from each container by multiplying Columns 2 and 3. Enter the volume in Column 4.

6. Multiply each value in Column 4 by a density of 0.06 ton /yd^3, and write the product in Column 5 for the appropriate waste category. The waste category for each container will have been previously identified by the truck driver or activity engineer as residential, commercial, or debris.

7. Add the weekly weights for each category of waste in Column 5. Enter the sums on line B.

8. Add the 3 totals on line B. Enter the sum on line C.

9. Divide each sum on line B by line C. Enter percentage as a decimal on line D.

10. Go to Action G.

TABLE F. ESTIMATE WASTE CATEGORY DISTRIBUTION BY TRUCK

(A) Truck no. ______________________

(1) Container no. or loc	(2) Size (yd^3)	(3) Pick-ups per week	(4) Volume per week (yd^3)	(5) Total weight per week (tons)		
				R*	C†	D§

(B) Total weight by category (tons) ____ ____ ____

(C) Grand total (tons) ______

(D) Percent by category (as decimal) ____ ____ ____

* R = Residential
† C = Commercial
§ D = Debris

Action G - Estimate Waste Generation (Weight) by Category

Complete Table G as follows:

1. Write the truck number for each refuse truck in Column 1.

2. If the truck carries only commercial or residential wastes, enter 1.0 on the appropriate line in Column 2. If the truck carries mixed wastes, enter the commercial and residential values from line D, Table F for each truck. Then enter the sum of the commercial and residential values in the last column of Column 3.

3. If waste generation records (weight) are available, determine the total seasonal waste generation rate for each truck using data from the previous year.

4. For each truck, multiply the waste generation data calculated in Step 3 or written in Column 4 of Table D by the decimal value for commercial waste in Column 2, and enter the product in Column 3. Repeat the same procedure but multiply by the commericial and residential decimal value in Column 2.

5. Add the individual truck commercial weights for each season. Enter the sum on line A. Repeat for the commercial and residential weights.

6. Go to Action H.

TABLE G. ESTIMATE WASTE GENERATION (WEIGHT)

(1) Truck no.	(2) Waste category distribution			(3) Waste weight per season							
				Winter		Spring		Summer		Fall	
	R*	C†	C+R§	C	C+R	C	C+R	C	C+R	C	C+R
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____	____
(A) TOTAL				____	____	____	____	____	____	____	____

* R = Residential
† C = Commercial
§ C+R = Commercial and residential

Action H - Estimate Average Daily Generation Rate

Complete Table H as follows:

1. If waste generation data (weight) by category are available, determine the previous year's seasonal generation rate for commercial waste and the sum of commercial and residential wastes.

2. Record these values or comparable values from the bottom line of Table E or Table G on the top line of Table H.

3. Divide each of these values by 65.

4. Enter these quotients on the bottom line of Table H.

TABLE H. AVERAGE DAILY GENERATION RATE ESTIMATE

	Winter		Spring		Summer		Fall	
	C	C+R	C	C+R	C	C+R	C	C+R
Seasonal average	___	___	___	___	___	___	___	___
Daily (TPD5) average	___	___	___	___	___	___	___	___

Appendix C

NCEL HRI MODEL FLOWCHART AND DATA SCREENS

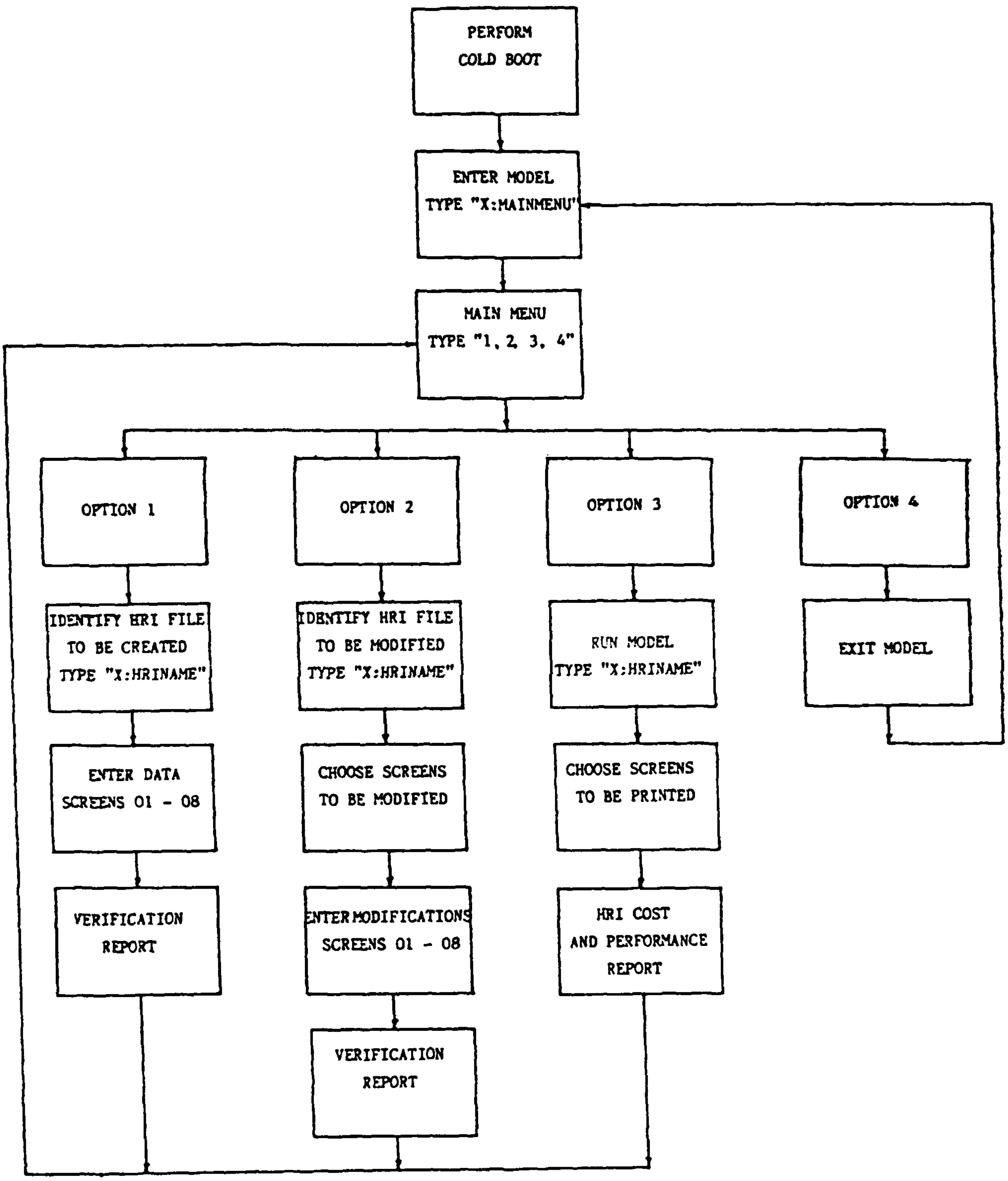


Figure C-1. Model flow chart.

```
***  GENERAL INFORMATION  ***              SCREEN 01
      CURRENT MONTH: 99        CURRENT YEAR: 99

           ***  NEAR-TERM FUTURE  ***
   NUMBER OF MONTHS BETWEEN ANALYSIS AND FUNDING: 99
    ANNUAL INFLATION RATES FOR THE FOLLOWING:
              CAPITAL EXPENDITURES: 99.9
                            ENERGY: 99.9
                    LANDFILL COSTS: 99.9
            ALL OTHER EXPENDITURES: 99.9

           ***  PROJECT LEAD TIME  ***
       ARCHITECT/ENGINEER(%)       CAPITAL COSTS(%)
YEAR 1       99.9                       99.9
YEAR 2       99.9                       99.9     (NOTE: PERCENTAGES
YEAR 3       99.9                       99.9       MUST ADD TO 100)
YEAR 4       99.9                       99.9
YEAR 5       99.9                       99.9

          ***  PROJECT ECONOMIC LIFE  ***
ECONOMIC LIFE OF HRI IN YEARS:  99          DISCOUNT RATE (%):  99
DIFFERENTIAL INFLATION RATES (%) FOR ENERGY:  99    AND LANDFILL:  99

           IS EVERYTHING CORRECT (Y/N)?: :
```

Figure C-2. Screen 01.

```
      ***  CAPITAL COST FOR EQUIPMENT  ***          SCREEN 02
                     YEAR $:   99
    ITEM                    COST          ITEM                      COST
RECEIVING:                9999999   QUENCH TANK WATER TREATMENT:  9999999
PROCESSING:               9999999   BOILER WATER TREATMENT:       9999999
STORAGE:                  9999999   INSTRUMENTATION:              9999999
RETRIEVAL:                9999999   CONTROL SYSTEM:               9999999
INCINERATION:             9999999   FIRE AND EXPLOSION SUPPRESSION
BOILER:                   9999999        EQUIPMENT:               9999999
ASH REMOVAL:              9999999   INITIAL SPARE PARTS INVENTORY: 9999999
AIR POLLUTION:            9999999   OTHER:                        9999999
                                            TOTAL:               99999999

        ***  CAPITAL COST FOR SUPPORT FACILITIES  ***
                     YEAR $:   99
             ITEM                            COST
        BUILDING:                           9999999
        UTILITIES:                          9999999
        EARTH WORK AND ROAD CONSTRUCTION:   9999999
        OTHER:                              9999999
                TOTAL:                     99999999
      ***  CAPITAL COST FOR CONSTRUCTION AND SETUP  ***
                YEAR$:  99        TOTAL: 9999999
           IS EVERYTHING CORRECT (Y/N)?: :
```

Figure C-3. Screen 02.

*** TOTAL CAPITAL COST *** SCREEN 03

YEAR $: 99 TOTAL: 99999999

*** CAPITAL COST FOR EXPECTED MODIFICATIONS ***

YEAR $: 99

DESCRIPTION OF MODIFICATION	MODIFICATION COST	ECONOMIC LIFE YEAR
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99
XXXXXXXXXX	9999999	99

*** CAPITAL COST FOR ARCHITECT AND ENGINEER SERVICES ***

PERCENTAGE OF ALL CAPITAL COSTS IDENTIFIED ABOVE: 99.9

IS EVERYTHING CORRECT (Y/N)?: :

Figure C-4. Screen 03.

*** LABOR COSTS *** SCREEN 04

YEAR $: 99

NO DOWNTIME

ASSIGNED TO OPERATION	ANNUAL MANHOURS(MHR)	RATE ($/HR)	TOTAL	DOWNTIME(%)
SUPERVISORY	99999	99.99	999999	999
SKILLED	99999	99.99	999999	999
UNSKILLED	99999	99.99	999999	999

TOTAL OPERATION LABOR COST: 9999999

PREVENTIVE MAINTENANCE	ANNUAL MANHOURS(MHR)	RATE ($/HR)	TOTAL
SUPERVISORY	99999	99.99	999999
SKILLED	99999	99.99	999999
UNSKILLED	99999	99.99	999999

TOTAL PREVENTIVE MAINTENANCE LABOR COST: 9999999

CORRECTIVE MAINTENANCE	MHR/CORRECT MAINT HR	RATE ($/HR)
SUPERVISORY	99.9	99.99
SKILLED	99.9	99.99
UNSKILLED	99.9	99.99

TOTAL CORRECTIVE MAINTENANCE LABOR COST: 9999999

IS EVERYTHING CORRECT (Y/N)?: :

Figure C-5. Screen 04.

```
                    *** COST OF CONSUMABLES ***                 SCREEN 05
                           YEAR $:  99
ELECTRICITY:            KWH/OPERATING HR: 9999        $/KWH:  9.999
                            KWH/DOWNTIME HR (% OF KWH/OP HR):  99.9
                      KWH/SCHEDULED NON-OP HR (% OF KWH/OP HR):  99.9

WASTE AND OTHER FUELS THAT OFFSET               VIRGIN GAS AND LIQUID FUELS
  USE OF VIRGIN FUELS
          GAL/TON     $/GAL      BTU/GAL        GAL/TON     $/GAL       BTU/GAL
LIQUID:   99.999       9.99      999999         99.999       9.99       999999
       1000 CF/TON  $/1000 CF  BTU/1000 CF   1000 CF/TON  $/1000 CF  BTU/1000 CF
GAS:      99.99       99.99      9999999        99.99       99.99       9999999
          TON/TON     $/TON      BTU/TON
SOLID:     9.99       99.99      9999999
SOLID:     9.99       99.99      9999999

MAKEUP WATER:   GAL/TON: 99999    $/1000 GAL: 99.99    OR ANNUAL TOTAL: 9999
CHEMICALS:
    CHEMICAL    UNITS/1000 GAL MAKEUP WATER   $/UNIT    OR    ANNUAL TOTAL
     XXXXX           99.99                     99.99              9999
     XXXXX           99.99                     99.99              9999
                           TOTAL ANNUAL COST OF CHEMICALS: 99999
                    IS EVERYTHING CORRECT (Y/N)?: :
```

Figure C-6. Screen 05.

```
                      *** OTHER COSTS ***                       SCREEN 06
  ITEM                        ANNUAL COST          YEAR $
REPAIR PARTS                     99999               99
SEWER                            99999               99
INSURANCE                        99999               99
PEST/VERMIN CONTROL              9999                99
RESIDUE DISPOSAL                               YEAR $: 99
    (ENTRIES MUST BE MADE FOR EACH OF THE FOLLOWING THREE GROUPS)
       TRANSPORTATION COST OF NONBURNABLE WASTE ($/TON-MILE):  99.99
       NUMBER OF MILES TO NONBURNABLE WASTE LANDFILL:          999
       TIPPING FEE AT NONBURNABLE WASTE LANDFILL ($/TON):      99.99
    OR COST OF LANDFILL DISPOSAL OF NONBURNABLE WASTE ($/TON): 99.99

       TRANSPORTATION COST OF ASH ($/TON-MILE):                 99.99
       NUMBER OF MILES TO ASH DISPOSAL LANDFILL:                999
       TIPPING FEE AT ASH DISPOSAL LANDFILL ($/TON):            99.99
    OR COST OF LANDFILL DISPOSAL OF ASH ($/TON):                99.99

       TRANSPORTATION COST OF ALL WASTE GENERATED ($/TON-MILE): 99.99
       NUMBER OF MILES TO LANDFILL:                             999
       TIPPING FEE AT LANDFILL ($/TON):                         99.99
    OR COST OF LANDFILL DISPOSAL OF ALL WASTE ($/TON):          99.99
                    IS EVERYTHING CORRECT (Y/N)?: :
```

Figure C-7. Screen 06.

*** OTHER COSTS *** SCREEN 07

ITEM	ANNUAL COST	ECONOMIC LIFE YEAR AND COST		TYPE COST (C,E,L, OR O)	YEAR $
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99
XXXXXXXXXX	9999999	99	9999999	X	99

IS EVERYTHING CORRECT (Y/N)?: :

Figure C-8. Screen 07.

*** OPERATING DATA *** SCREEN 08

TONS OF NONBURNABLE WASTE/TON OF WASTE:	9.999
ESTIMATE OF HRI COMBUSTION RATE (TONS/HOUR):	9.99
HRI TURN-UP CAPABILITY (PERCENT ABOVE NORMAL FIRING RATE):	99.9
TONS OF ASH (BOTTOM OR FLY)/TON OF BURNED WASTE:	9.99
$/MBTU OUTPUT OF FOSSIL FUEL BOILER AND YEAR $:	99.99 99
THERMAL EFFICIENCY OF FOSSIL FUEL BOILER (%):	99.9
HEATING VALUE OF BURNABLE WASTE (BTU/TON):	99999999
HRI FURNACE TYPE (R=REFRACTORY, W=WATER WALL):	X
THERMAL EFFICIENCY OF THE HRI (%)	99.9
ESTIMATE OF HRI TOTAL ANNUAL DOWNTIME DUE TO FAILURE (%):	99
ESTIMATE OF HRI ANNUAL NUMBER OF FAILURES:	999
ESTIMATE OF MAXIMUM HRI DOWNTIME (HOURS):	999
TIME REQUIRED TO COMPLETE A DAYS DELIVERY (HOURS):	99
STORAGE SPACE AVAILABLE AT HRI (TONS):	999
HRI OPERATING SCENARIO:	
1=BURN 2 SHIFTS, 5 DAYS 2=BURN CONTINUOUSLY, 5 DAYS	9
3=BURN 2 SHIFTS, 7 DAYS 4=BURN CONTINUOUSLY, 7 DAYS	
5=BURN CONTINUOUSLY, 4 DAYS, FOLLOWING DAY 1 RECEIPT	
HRI PLANNED ANNUAL OPERATING WEEKS:	99

IS EVERYTHING CORRECT (Y/N)?: :

Figure C-9. Screen 08.

INFLATED PER TON COST OF DISPOSING WASTE OF THE TYPE GENERATED AT THE SITE TO THE LANDFILL:	$31.73
INFLATED PER MBTU COST OF THE FOSSIL FUEL BOILER TO WHICH THE HRI IS BEING COMPARED:	$10.36
TONS OF TRASH BURNED ANNUALLY BY THE HRI:	10,800
MBTUS PRODUCED ANNUALLY BY THE HRI (CONSIDERING NO DOWNTIME):	4.66E+04
VIRGIN FUEL OFFSET ANNUALLY BY THE HRI IN BARRELS-OF-OIL-EQUIVALENT:	8,114
LANDFILL SPACE CONSERVED ANNUALLY BY THE HRI IN TONS:	7,884
COST OF USING A BOILER TO PRODUCE THE ANNUAL NO-DOWNTIME QUANTITY OF STEAM PRODUCED BY THE HRI AND LANDFILLING ALL WASTE:	$949,623
INFLATED TOTAL CAPITAL COST OF THE HRI (INCLUDES EQUIPMENT, SUPPORT FACILITIES, AND CONSTRUCTION AND SETUP):	$2,259,450
UNIFORM ANNUAL COST OF THE HRI (THE COST OF CAPITAL, MODIFICATIONS, LABOR, CONSUMABLES, RESIDUE DISPOSAL, DOWNTIME, AND OTHER COSTS SPREAD OVER THE ECONOMIC LIFE OF THE HRI):	$802,985
ANNUAL NO-DOWNTIME COST OF THE HRI (THE TOTAL OF NO-DOWNTIME COSTS SPREAD OVER THE ECONOMIC LIFE OF THE HRI):	$787,041
DISCOUNTED LIFE CYCLE COST OF USING A BOILER TO PRODUCE THE LIFE CYCLE NO-DOWNTIME QUANTITY OF STEAM PRODUCED BY THE HRI AND LANDFILLING ALL WASTE (COSTS DISCOUNTED TO THE POINT OF INITIAL FUNDING):	$8,624,650
DISCOUNTED LIFE CYCLE COST OF THE HRI:	$5,282,240
DISCOUNTED LIFE CYCLE COST OF AUXILIARY FUELS USED BY THE HRI:	$72,215
DISCOUNTED LIFE CYCLE COST OF NONCOMBUSTIBLE WASTE, ASH, AND SCHEDULED DOWNTIME WASTE DISPOSAL:	$1,613,510
DISCOUNTED LIFE CYCLE COST OF HRI DOWNTIME:	$147,695
DISCOUNTED LIFE CYCLE COST OF THE HRI PER TON OF WASTE FIRED:	$24.45
DISCOUNTED LIFE CYCLE SAVINGS OF THE HRI PER TON OF WASTE FIRED:	$23.96
DISCOUNTED LIFE CYCLE COST OF THE HRI PER MBTU PRODUCED:	$6.30
DISCOUNTED LIFE CYCLE SAVINGS OF THE HRI PER MBTU PRODUCED:	$6.17
DISCOUNTED LIFE CYCLE SAVINGS OF THE HRI:	$5,175,440
HRI SAVINGS-TO-INVESTMENT RATIO:	+2.83
PAYBACK PERIOD IN YEARS (INCLUDES PROJECT LEAD TIME):	10.2

Figure C-10. HRI cost and performance report.

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