To the Graduate Council:

I am submitting herewith a thesis written by Jeffrey E. Christian entitled "Resource Recovery for Institutions: A Technical, Environmental and Economic Feasibility Analysis for the Oak Ridge National Laboratory." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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RESOURCE RECOVERY FOR INSTITUTIONS:
A TECHNICAL, ENVIRONMENTAL AND ECONOMIC
FEASIBILITY ANALYSIS FOR THE OAK RIDGE NATIONAL LABORATORY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jeffrey E. Christian

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To Beverly, who stood by all this high quality waste until it rose to knee deep, waist high, shoulder height...

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ABSTRACT

The purpose of this analysis is to examine resource recovery options for one institution, the Oak Ridge National Laboratory, very closely and to make available the analysis procedure and findings to other institutions. A host of resource recovery options are identified: fiber recycling, refuse derived fuel (RDF) co-fired with coal, district heating connected to an incinerator with heat recovery and modular incineration. Recycling was found to save more energy than incineration, however at a substantial cost penalty. RDF requires a waste flow rate in excess of 100 TPD, experienced mechanics, extensive dust control equipment and a high operating and maintenance budget to maintain the refuse processing facility as well as the modified coal boiler. ORNL has a 6 TPD refuse load and another 21 TPD attainable from two other nearby Union Carbide owned facilities. A small modular incinerator facility with the capacity to burn about 1300 lb per hour, and located 2.5 miles from the main ORNL facility serving an isolated experimental facility, would have a likely payback of less than 7 years. The facility could import about 12 - 14 TPD from Y-12 and K-25, and operate 3 shifts per working day. The energy displacement would save about $260,000 per year or about 230,000 gallons of oil. A decision-risk analysis demonstrates how to quantify the risks involved in resource recovery for institutions and incorporate the perceived risks into the decision to invest in small scale resource recovery.

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INTRODUCTION

This study has two objectives. The first being to determine alternatives for the Oak Ridge National Laboratory to convert refuse to useful energy, and recommend a sound technical, environmental and economic solution. The second objective is to relate the study procedure and findings to other institutions faced with future energy supply uncertainties and an interest in exploring refuse as an energy supply option.

A host of resource recovery alternatives are explored; recycling,with separation at the source, modular incineration with heat recovery, RDF co-fired with coal, and steam purchase from a large nearby municipal incinerator. Financial and technical aspects of each of these technologies is presented.

Three resource recovery options are studied in more detail for ORNL application. The first being modular incineration with heat recovery, located adjacent to existing oil fired boilers, used to provide space heating and process water needs at a remote experiment station on the ORNL reservation. The second is a modular incinerator with heat recovery supplementing the ORNL coal-fired steam plant steam supply. The third alternative involves providing refuse derived fuel (RDF) to the ORNL steam plant so that RDF can be co-fired with coal in an existing coal fired boiler. A decision-risk analysis is used to tradeoff the advantages and disadvantages of each alternative and and by inserting perceived risks selects the best alternative.

Finally, recommendations will be offered to ORNL management. The recommendations are envisioned to aid preparation of a purchase requisition for the necessary equipment and labor to install the equipment and to obtain environmental permits.

I. PROBLEM DEFINITION

Research centers, universities, office complexes and other large institutions are faced with rising costs for needed energy and possible shortages of some fossil fuel supplies in the future. Many of these institutions have large quantities of solid waste which could be used for some element of resource recovery. In general, institutions have a relatively more homogenous waste stream than municipal refuse and through proper handling, a high quality waste could be obtained at the generation sources and recycled or incinerated with waste heat recovery at less difficulty and expense than large municipal resource recovery projects. However, any investment in on-site resource recovery should be undertaken if the investment is cost effective. If on-site resource recovery is not found to be technically, environmentally and financially sound, the responsibility for proper resource recovery unfortunately falls in the hands of frequently overburdened local governments.

Under the Solid Waste Disposal Act of 1965 (P.L. 89-272) and the Resource Recovery Act of 1970 (P.L. 91-512), EPA developed a set of guidelines which were intended to apply only to federal agencies and their facilities. Section 211 of the Resource Recovery Act, and Executive Order 11752, made the "requirements" section of the guidelines mandatory for federal agencies.

The resource recovery facility guidelines presently apply to federal facilities generating more than 100 tons per day of solid waste. RCRA further mandates federal, state, and local procuring agencies to use solid waste management services which maximize material and energy recovery. And, if the agencies existing facilities generate their own heat or electricity, they must use waste-based fuel to the extent practicable. (If state and local agencies do not comply, they will not receive funding under RCRA.)

The Oak Ridge National Laboratory is a large institution faced with rising costs and threatening fossil fuel shortages. Therefore, they are interested in reducing their demand for fossil fuels in whatever means possible, provided the investment is economically and environmentally acceptable. A second order incentive at ORNL is that Union Carbide owns and operates the facility, and being a chemical producing industry they realize the added value of the world's remaining reserves of oil, gas and coal for chemical feed stock.

II. WASTE-TO-ENERGY FOR INSTITUTIONS

A. General

If institutions could dispose of their own waste internally by either reusing or recovering useful energy, two of the major problems many other Resource Recovery Projects have, can be minimized.

First, it is much easier to get a good estimate of whether there is sufficient refuse available to support a resource recovery project and whether or not it can be committed in the long term to a waste-to-energy facility.

Secondly, institutions are in a much better position to determine whether realistic long-term use for the recovered energy exists, than if one had to depend on the uncertainties involving the market.

The action on the part of institutions using their own waste internally is compatable with large municipal scale resource recovery projects. One of the first steps involved in laying out plans for a large waste-to-energy facility is to encourage a reduction in waste throughout the community wherever practical. A simile exists between waste-to-energy facilities and solar energy. The first step is to reduce the demand for energy so the solar system is affordable.

Institutions generally have a very high quality waste stream compared to municipal refuse, high energy content, lower moisture and fewer noncombustible materials. In some cases, the smaller, higher quality waste stream can be converted to useful energy forms more cheaply than mixing this waste with general municipal waste and feeding through a large municipal waste-to-energy facility. The heat content of institutional waste stream consisting of "type 1" waste is around 15,120 KJ/Kg (6500 Btu/lb) compared to municipal waste consisting of primarily type 2 waste with a heat content of around 10,000 KJ/Kg (4300 Btu/lb).

Institutions frequently have internal mechanisms which facilitate communication and a greater degree of control over their waste stream than municipalities. This control can be used to institute waste disposal practices which enhance the performance of prescribed waste-to-energy facilities.

This report focuses on three particular types of institutions: research facilities, universities, and office complexes. The reason these three institutions are singled out lies primarily with the fact that between 70-90% of their waste stream weight is paper and wood.[1] Much of the information contained within this report may be applicable to other institutions, such as hospitals and prisons, however, the special waste disposal problems these institutions generally have, are not considered. Hospitals generally have a high fraction of plastics and pathological waste. Prisons frequently generate a large fraction of metals.

B. Universities

Many variables affect the quantity and composition of the solid waste stream generated at universities.[2] These same variables tend to affect the energy needs of the university:

- Size
- Location
- Type of schools within the university (medical, agricultural, engineering)
- Number and type of university services (health services, libraries)
- Proportion of students living on campus

Frequently universities have central heating plants which distribute heat to all buildings on campus and also many universities collect their own refuse. Part of the success of waste-to-energy systems in Europe is due to the same entity having responsibility for both energy production and solid waste collection and disposal. Universities frequently have both responsibilities, however, they tend to lack working capital to set in place energy conservation opportunities.

The national energy act of 1978 recognizes the capital needs of schools and hospitals and opens up new opportunities to universities to arrange financing for waste-to-energy projects in the near future.[3] The first steps to be taken by the universities will be to reduce energy needs. Once the loads are reduced through insulation and other appropriate building alterations, university waste-to-energy systems may be capable of supplying a significant fraction of the total energy needs.

The national energy act also provides considerable incentives to replace conventional fossil fuels with renewable energy forms, and secondly, conversion from gas and oil to coal burning facilities. Siting of small coal burning facilities generally involves considerable cost in coal handling, air pollution equipment and ash disposal. There may be a size range between those universities which are large enough to convert to coal and those too small to switch from the less expensive oil and gas burning facilities. This niche may be best filled with waste-to-energy facilities.

For future discussion purposes, the university used to represent this institutional type will be The University of Tennessee (UT), Knoxville. UT presently enrolls about 35,000 students and faculty and has a central coal plant which distributes steam year round to most of the buildings on campus.

C. Research Facilities

Research facilities are different from universities. First of all, there are fewer people actually living within the facility, thus the waste stream characteristics differ. Secondly, the energy demand profile differs. The research facility generally has higher energy needs during daylight hours consistent with the 8:00 a.m. to 5:00 p.m. five day per week schedule. Universities on the other hand display heat load profiles frequently peaking during evening and early morning hours, and the weekend loads remain high.

Many research facilities have fairly high process energy needs offering a potential demand for thermal energy year around. Owing to the nature of research and development, frequently exotic chemicals and metals are used at research facilities. Hazardous materials are kept separate from the waste stream which is sent to the local landfill. This practice helps produce an even more attractive waste stream for waste-to-energy conversion processes.

A second order waste problem frequently experienced by research facilities and universities is the disposal of crank case oil. Conceivably a single facility could be designed to handle both the general refuse waste stream as well as disposal of these waste oils in an environmentally acceptable manner.

For future discussion purposes the research facility used to represent this institutional type will be the Oak Ridge National Laboratory (ORNL), located in a rural area, west of Knoxville, Tennessee. ORNL presently employs about 6,000 employees and has a central coal plant which distributes 18,270 KPa (250 psig) steam to most of the larger buildings at the ORNL site.

D. Office Complexes

Office complexes generally tend to have the highest quality waste stream for waste-to-energy processing. Unfortunately the need for thermal energy in office buildings generally tends to be lower.

Offices generally have a higher space cooling load and a lower space heating load than other types of buildings. One big reason for the lack of space heating demanded by office buildings is the high heat contribution from lighting. In the past, office buildings frequently installed lighting equivalent to 4-6 watts per square foot of floor area. With the re-examination of energy loads, lighting levels are being reduced. More efficient light bulbs and heavy use of task lighting can reduce lighting loads to 1-2 watts per foot^2. This reduction in lighting loads may increase the space heating demands of office buildings to the point where oil and gas consumption increases and possibly forces additional boiler capacity to be installed. In very large office buildings the introduction of energy conservation opportunities ironically may cause an increase in space heating loads, presenting waste-to-energy facilities an attractive market.

For future discussion purposes the office building complex used to represent this institutional type will be the Tennessee Valley Authority (TVA) Towers located in downtown Knoxville. The central heating and cooling equipment is located on top of the towers. The heat source is an electric powered heat pump backed up by an oil fired boiler.

III. PRESENT REFUSE LOADS AND COST

A. General Procedure

Two key questions which must be given considerable attention: (1) Is there sufficient waste to support a resource recovery facility? and (2) can this waste stream be committed for the life of the project? Generic "generation rates" are available in the literature.[4] Universities are reported to generate about .45 Kg (1 lb) per student per day with a range from .4 Kg (0.86 lb) per student per day to .8 Kg (2 lb) per student per day. Offices are reported by one source to produce .68 Kg (1.5 lb) per office worker per day,[5] and by another source .45 Kg (1 lb) per 9.3 m^2 (100 ft^2) per day.[4] These rates should be used very cautiously. The only way to be certain of a given waste stream is to perform an on-site study. Occasionally records are kept in more than one place. If possible, check with collection personnel as well as those responsible for disposal records. Cross check weights and review past years waste disposal rates and attempt to understand any fluctuations that may have occurred. Some institutions contract out the refuse collection responsibilities to a local collection company. Truck trip reports and actual weights should be made available.

If inadequate data exists, request that collection trucks be weighed for a period of time long enough to determine average weights; one to two months should be adequate. Offices and research facilities waste loads do fluctuate seasonally. Summer, Christmas, Easter and quarter breaks all result in considerably reduced waste generation rates from universities.

Occasionally, very good records are kept on the number of truck trips, but nothing on truck weights. The temptation is to use rated packing densities and reported carrying capacity volumes to estimate the average truck weight. Frequently, trucks travel to the disposal site partially filled. The tendency is to overestimate the actual waste load.

B. ORNL Refuse Load

B.1 Quantity

Since 1977, ORNL has disposed an average of 1340 metric tons (1475 tons) per year of predominately paper and wood waste in the Y-12 Landfill. Table 3.1 shows the tons of refuse generated and landfilled from 1969 to 1979.[6] The step change from 1975 to 1976 is believed to be due to ORNL disposing a portion of their refuse in a disposal site near the ORNL site which was ordered closed by the Environmental Protection Agency. The waste loads reported in the last three years do not represent all of the waste generated at ORNL. Some computer paper and cards are collected separately and recycled. Ceramics, metals and glass are collected separately and disposed of in the "contractors" landfill located near the ORNL site. Volatile chemicals are also collected and disposed of separately.

About half of the incoming computer paper and cards used at ORNL are recycled. A number of recycling stations have been designated nearby most of the computer users around the laboratory. White plastic

Table 3.1. Tons per year of refuse from ORNL disposed in the Y-12 landfill

Year (Oct.-Sept.)	Tons
1969	540
1970	420
1971	550
1972	380
1973	540
1974	330
1975	280
1976	1000
1977	1490
1978	1480
1979	1450

containers equipped with wheels are used to transport the recycled paper and cards from the recycling stations to the loading docks where the materials are taken to storage. The cards and papers are trucked to Knoxville Fiber in Knoxville once every six months. In August 1978, ORNL was recycling about 7 tons of computer paper and cards per month.[7]

Disposal of bottles which contain only traces of volatile chemicals had presented a safety hazard to the Y-12 landfill operator when the landfill was first put into service. There were several fires and explosions that were attributed to chemicals remaining in discarded bottles. To eliminate this hazard, special containers have been placed in the laboratory areas to be used only for the disposal of chemical bottles. The discarded bottles are taken to the hazardous materials burial ground where they are covered without compaction.[8]

All metals and ceramic materials are also separated from the primary refuse stream at ORNL. Separate bins are provided for disposal of metals and ceramics and this waste stream is disposed of in the construction contractors landfill located near ORNL.

To account for seasonal variations, monthly delivery data was examined. Monthly weight data was not available. However, an exact count of truck and container deliveries along with average weights of each type of delivery truck were available. Table 3.2 shows monthly truck trips by truck type, along with estimated weights.

To obtain the average refuse load for each type of truck, weights were recorded for two-one month periods. An average of 125 metric tons per month was delivered to the landfill between May 1978 and June 1979.

Earlier estimates of solid waste loads at ORNL used waste generation rates reported in the literature.[9] Office buildings are usually reported to generate 0.68 Kg per office worker per day. Using this rate of 0.68 Kg times 2830 which is the reported number of office workers at ORNL in September 1978, one could conclude ORNL generates 2.1 short tons per day instead of the actual 6.7 tons/day estimate based on sample truck weights and actual truck trip reports. Generic waste generation rates should be used cautiously.

B.2 Hauling and landfill cost

The predominately paper and wood waste from ORNL is disposed of in the Y-12 Landfill, which is utilized by two other Oak Ridge Facilities, the Y-12 Plant and the Oak Ridge Gaseous Diffusion Plant.

Table 3.2. ORNL monthly refuse load data

Month	Large Compactor[a] # of Trips	Small Compactor[b] # of Trips	Trash Truck[c] # of Trips	Laundry Truck[c] # of Trips	Dempster Dumpster[c] # of Trips	Total Delivered Weight Tons
June	2	22	34	0	3	120
July	2	26	19	0	2	128
August	2	24	31	0	1	126
September	2	35	25	0	1	166
October	3	38	33	0	3	183
November	2	25	40	0	4	136
December	2	23	37	0	4	127
January	2	30	34	0	4	153
February	2	27	31	0	4	139
March	2	32	15	0	4	150
April	2	23	34	0	5	125
May	2	21	7	22	4	114
Total	25	326	340	22	39	1667

[a]Average measured weight of large compactor load = 8.65 ton.

[b]Average measured weight of small compactor load = 3.9 ton.

[c]Average estimated weight = 0.5 ton.

The Oak Ridge Sanitary Landfill is located on a 100-acre tract about two miles west of the Y-12 Plant (see Figure 3.1), 8.5 miles from the ORNL site.

Table 3.2 shows a total of 752 refuse truck trips from June 1978 to May 1979 from ORNL to the Y-12 landfill. In 1972, the reported labor cost for transporting the large compactor trailer from ORNL to Y-12 was $36 per trip. Escalation to 1980 dollars using 10% per year equals $65 per trip. Assuming that $65 per trip is representative of the cost to make one trip with the large compactor. The resulting labor hauling cost for 25 trips converts to $1,625 per year. For the other trucks assuming 35 mph, 17 miles round trip, two men, $18/hour and 727 trips, the resulting labor cost is $12,824.

The average operating cost for the refuse trucks are $.59/mile.[10] The 752 trips require 12,784 miles or $7,545/year for vehicle maintenance and depreciation.

The total labor and equipment cost for hauling refuse from ORNL to the Y-12 landfill is estimated at $13.20 per ton.[10] Assuming the average fleet mileage of refuse delivery trucks is 6 mpg, the refuse trucks consume about 2,130 gallons of gasoline per year.

In 1972, landfill costs were $8.05 per ton.[11] Today the Y-12 landfill costs are $15.30 per ton.[12] ORNL contributes approximately 22% of the total refuse buried in the Y-12 landfill. The overall landfill costs reported for fiscal year 1979 are $40,400 for equipment and maintenance, $61,000 for labor and $12,000 for materials (rock, grass seed, signs).

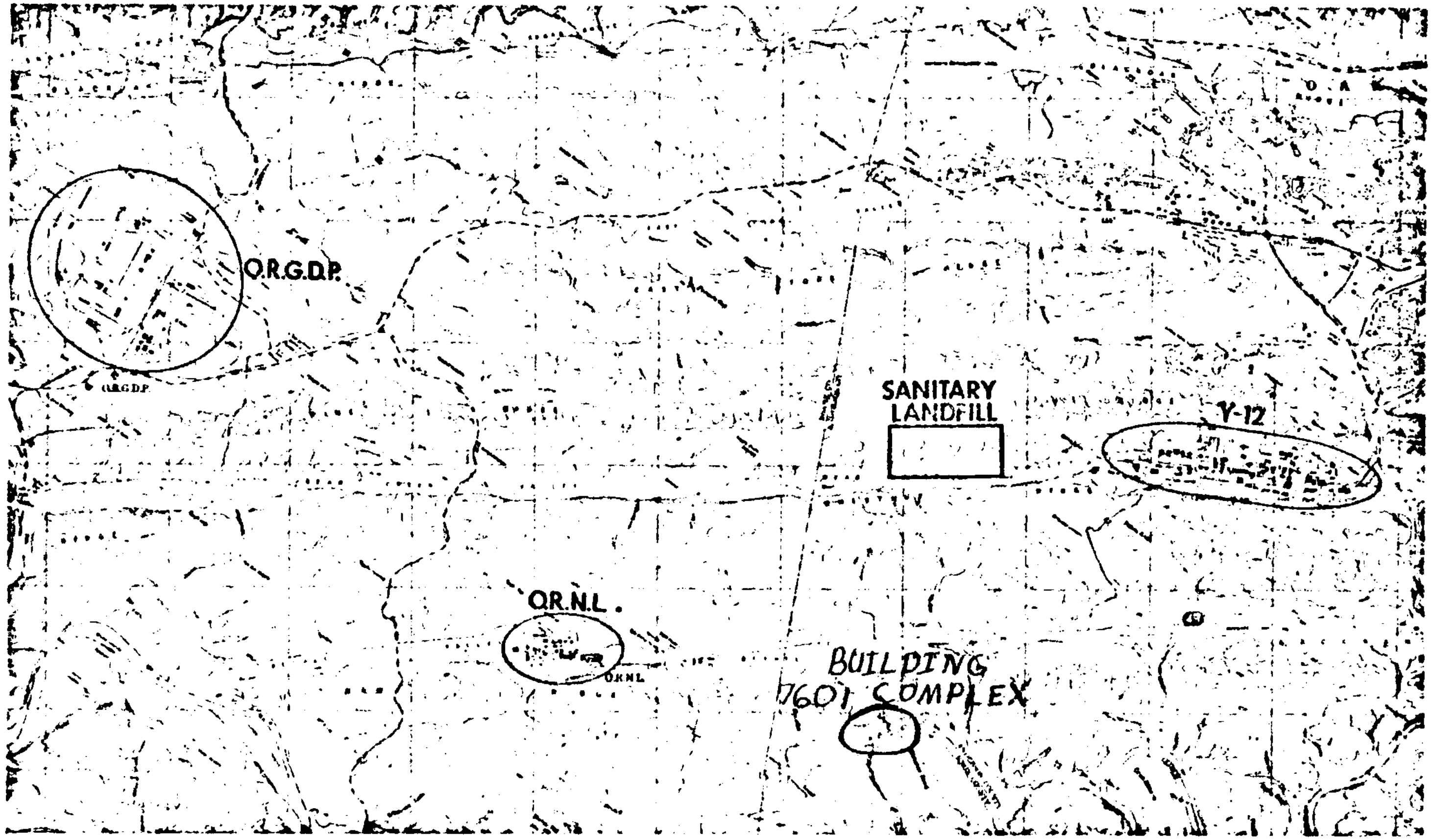


Figure 3.1. Sanitary landfill location.

IV. FUTURE COST OF CONTINUING EXISTING PRACTICE

A. General Procedure

Predicting future costs of both landfilling and energy is difficult. However, siting landfills is a growing issue for many communities. In fact this task has grown to such a problem that many communities are using landfill fees not only to cover rapidly escalating landfill costs, but also to generate additional revenue.

Close-in garbage disposal sites are slowly reaching capacity. With continuing strict state licensing enforcement, required by the Resource Conservation and Recovery Act of 1976 close-in garbage disposal sites will eventually become nonexistant.

Local costs for solid waste disposal are rising dramatically. The former charge of $2 per ton for dumping has increased to somewhere between $6 and $25 per ton for sanitary landfilling.[13]

All states are not pursuing increased control of sanitary landfilling. Gershman and Price conducted a most interesting survey which attempted to rank states according to the degree of vigor of enforcement programs.[13] They assigned credits based on a set of criteria which indicated effort and results. One credit was assigned to those states which increased their 1977 enforcement budget over $500,000 from the 1976 budget. They gave no credit to states with less than $500,000 increase, and subtracted a credit for any state whose budget had decreased from 1976 to 1977. Each state which installed more than two impermeable landfill linings received one credit and each state reporting more than two leachate treatment facilities was given one credit. Finally, they assigned a credit to any state reporting more than 20 landfill closings since 1976.

Based on this analysis, one can estimate which states have the strictest land disposal enforcement policies and most likely the higher disposal cost. The states with more stringent landfill enforcement policies in general have higher land disposal costs. Michigan, New Jersey, Pennsylvania and Wisconsin scored highest, with four credits each. Florida and New York totaled three each. California, Colorado, Illinois, Kentucky, Massachusetts, Minnesota, Montana, Oregon, Tennessee, Texas, Virginia and Washington each scored two credits. Thirteen states had one, and the remaining nineteen had none.

As for energy costs, the Federal Register (April 30, 1979, Part IV Proposal Rules) contains tables with projected energy prices and escalation rates for each region, sector and fuel type.

The escalation rates presented in these tables are suggested by DOE for use by all Federal Facilities analyzing the cost savings from energy conservation opportunities. DOE considered the use of projected marginal energy price escalation rates. These reflect the replacement or marginal costs of producing and delivering additional supplies of energy rather than average retail prices. They recognize that such prices would reflect the cost savings to the nation from energy conserving actions, rather than simply the cost savings to the Federal Government. DOE plans annually to update these forecasts of energy prices, as well as the base year energy prices indicated in the

Federal Register (Vol. 44, No. 84/April 30, 1979). Possibly this year's forthcoming escalation rates will better reflect marginal costs.

B. ORNL Future Refuse Loads and Cost

B.1 Loads

Currently, ORNL generates about 1,475 tons of predominately paper and wood waste each year. Three events could take place in the future at ORNL to change the refuse load. The first concerns growth. Currently, the ORNL site has 5,490 employees about 100 people per year will be added to the staff for the next seven years[14] (a growth of about 13%). The second relates to employee relocation. ORNL will be constructing a new energy management building located near Building 4500 N. The completion of this building will allow a few of the 1,000 ORNL employees occupying office and laboratory space in the Y-12 facility to relocate at the ORNL site. The addition of these employees brings the entire ORNL ranks to about 6, 200.

The third event pertains to the use of microfilm. Presently ORNL produces about 2.15 pounds of refuse per person per working day. Using this same rate for the 6,200 employees expected by 1987, results in an annual refuse load of 1,667 tons. The increasing use of microfilm is assumed to stabilize the per capita waste generation rate. Microfilm is presently being used in the libraries, in computer output applications and in reports.

B.2 Cost

The hauling costs are currently about 85% labor and 15% petroleum products. The labor is assumed to have a real escalation rate of 1% per year. The real escalation rate is the percentage increase above and beyond the rate of inflation. All costs are in constant 1980 dollars. Oil is assumed to escalate by about 4% per year, according to the DOE guidelines presented in the April 30, 1979 Federal Register. By 1987, the hauling cost in current 1980 dollars should equal about \$14.75/ton.

The landfill costs are assumed to escalate 1% per year. By 1987, the current landfill cost will escalate to \$16.52/ton. There are additional capital investments required by the landfill which should be factored into the landfill cost. Within the next year, the landfill will be purchasing a 50% interest in a piece of excavating equipment priced at \$300,000 (this machinery will be shared 50/50 with the Y-12 burial grounds). The annuallized cost for this equipment will be about \$40,000. Half the cost of this item converts to an additional cost per ton at the Y-12 landfill of about \$2.00.

Within the next 3 to 4 years, a new end-loader and dozer will be purchased for the landfill facility at a cost of about \$280,000. The annuallized cost for this equipment will be about \$32,000 or about \$3.20/ton.

Another event which will take place shortly at the Y-12 landfill is state licensing. Currently, the facility is not licensed. Conceivably some type of leachate treatment may also by required. Jim Bailey, the engineer responsible for the Y-12 landfill, estimates about $23,000 per year or about $2.30/ton for surface water treatment. One more improvement on the landfill facility within the next two years might be the installation of a leachate collection system. At this time the cost per ton of collecting and treating all water which leaches through the landfill is unknown. Accounting for the near future landfill equipment needs, the additional cost amounts to $7.50/ton. By 1987, the total landfill cost at the Oak Ridge Central Landfill is estimated to be $24.00/ton. This value does not account for the possible cost of clay liners and leachate collection, nor the cost of setting up another landfill site. The current landfill has about ten years remaining before reaching its capacity.

V. SELECT ALTERNATIVES

A. Resource Recovery Options for Institutions

A.1 Recycling and separation at the source

Universities, offices and research facilities generate wastes that are mostly paper and corrugated cardboard. All paper types are not treated equally. Computer cards presently bring $130/ton, computer paper-$58.25/ton and mixed office paper-$6/ton. All the waste computer paper and cards at ORNL could generate a revenue of $10,876.50. The estimated cost of labor and collection equipment to recycle half of the paper and cards rather than landfill them has been estimated to be $446/ton. The reason this procedure is so costly is due to the fact that computer paper and cards must first be separated from each other and from extraneous materials, and then the computer paper and cards must be neatly boxed and tied down to skids. The local fiber recycling market will not accept the materials otherwise. The cost involved is entirely for labor. It amounts to 3 laborers, 2 days per week, at $15.00 per man hour. Since source separation requires so much labor, the costs are difficult to recover considering today's market prices for recycled fiber.

The Tennessee Valley Authority Towers in Knoxville with about 3,000 office workers have instituted a paper recycling program. All high grade fiber is separated from the other office waste by having separate plastic holders on every desk. The janitorial people collect the paper separate from the other office trash.

Computer paper, cards, high grade typing paper and xerox copy paper are all combined into a single waste stream, resulting in revenues of around \$6/ton. Currently, TVA recycles about 1.5 tons/day. If only 300 pounds of computer paper could be recycled each day the same \$9 revenue would result. Clearly, office paper recycling programs do not seem to be "cost effective." However, many feel that rather than landfilling, recycling attempts ought to be an everyday cost of operating an office, owing to the environmental benefits.

U.T. up until 1977, had a paper recycling program. Demster Dumpsters for paper waste only, were distributed throughout the campus. A separate collection vehicle gathered up the contents. No costs were available on this program. The revenue generated could not pay for the refuse labor and equipment, and the program was discontinued.

On an energy basis, paper has a higher BTU value when it is reused as paper than when it is used as a fuel. For instance, a ton of recycled newsprint used to replace virgin material in paper production saves 12 million BTU per ton. Used as a fuel, newsprint begins with a heating value of around 16 million BTU per ton, but loses about 45% of this potential through conversion. To recycle the 1,000 pounds per day that ORNL is currently collecting, a total of 3.5 gallons of gasoline per ton is needed to get the paper to the Knoxville Fiber scrap dealer. Paper recycled saves about 30% more energy than if the paper is incinerated with heat recovery.

A.2 Modular incineration with heat recovery

A.2.1 Description

A modular incinerator shown in Figure 5.1 is a controlled air combustion unit with three main components: the primary combustion chamber which operates under substoichiometric conditions, a secondary combustion chamber, operating under excess air conditions (shown by Figure 5.2), and a heat recovery boiler. Each component is assembled and packaged in the factory, requiring only electrical, fuel, water and exhaust gas duct connections for installation.

A very brief description of the major components of a modular incinerator is provided in this section. For further information, there are two studies which offer an in depth description of this technology.

In 1976, Ross Hofmann and Associates prepared an "Evaluation of Small Modular Incinerators in Municipal Plants" for the Office of Solid Waste Management U.S. Environmental Protection Agency.[15] This report was the first document released by the EPA which illustrated the potential benefits of "small" incinerators utilizing a controlled air principle. Extensive testing was undertaken at three different installations located in Pahokee and Orlando, Florida and Siloam Springs, Arkansas. Energy conversion efficiencies auxiliary fuel requirements, stack gas emissions, and capital, operating and maintenance requirements for these facilities are documented.

A second study conducted in 1979 by Richard Frounfelker, from the Systems Technology Corporation, titled "Small Modular Incinerator Systems with Heat Recovery," investigated the performance of two small

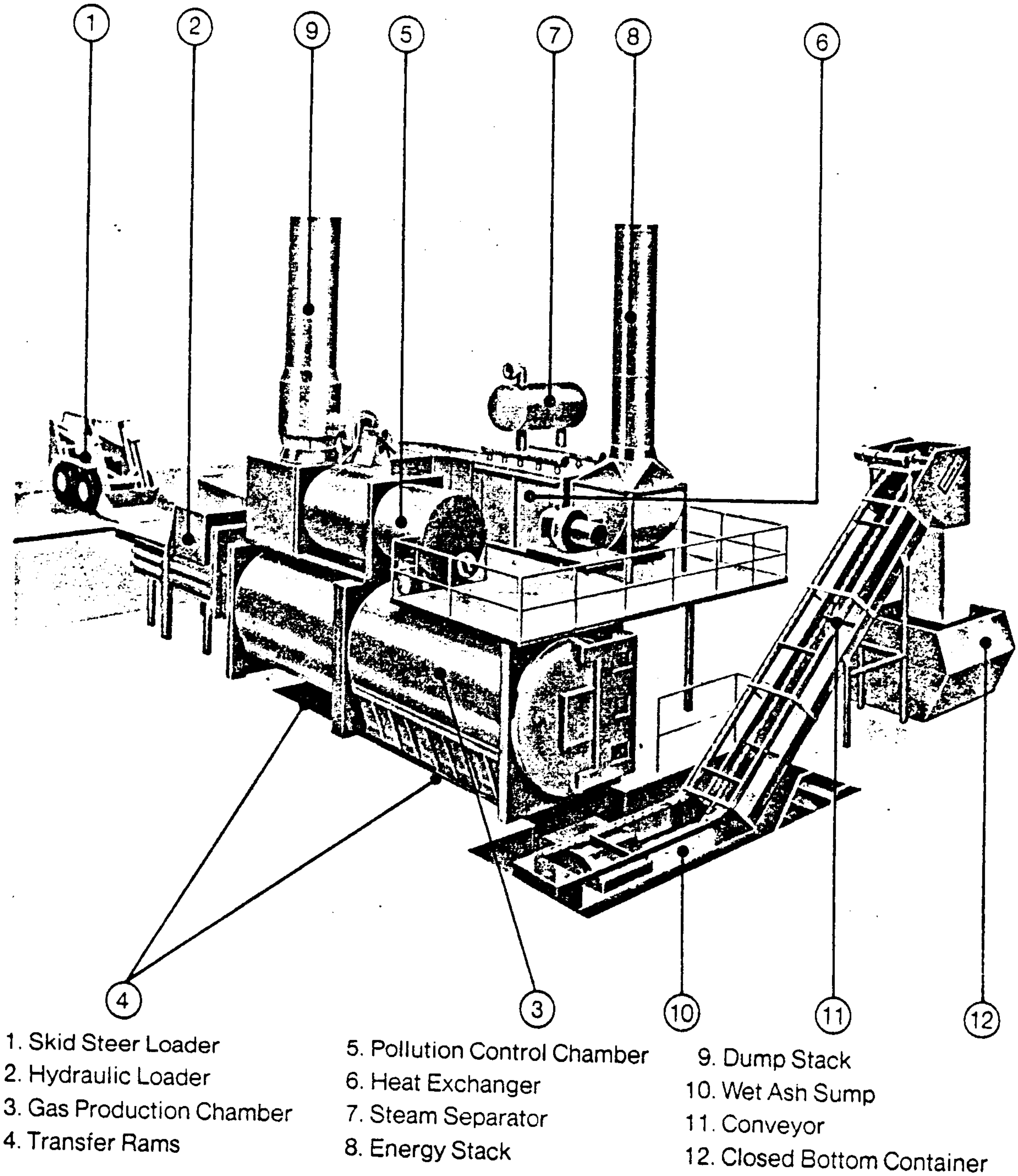


Figure 5.1. Modular incinerator.

Source: Consumat Systems, Inc.

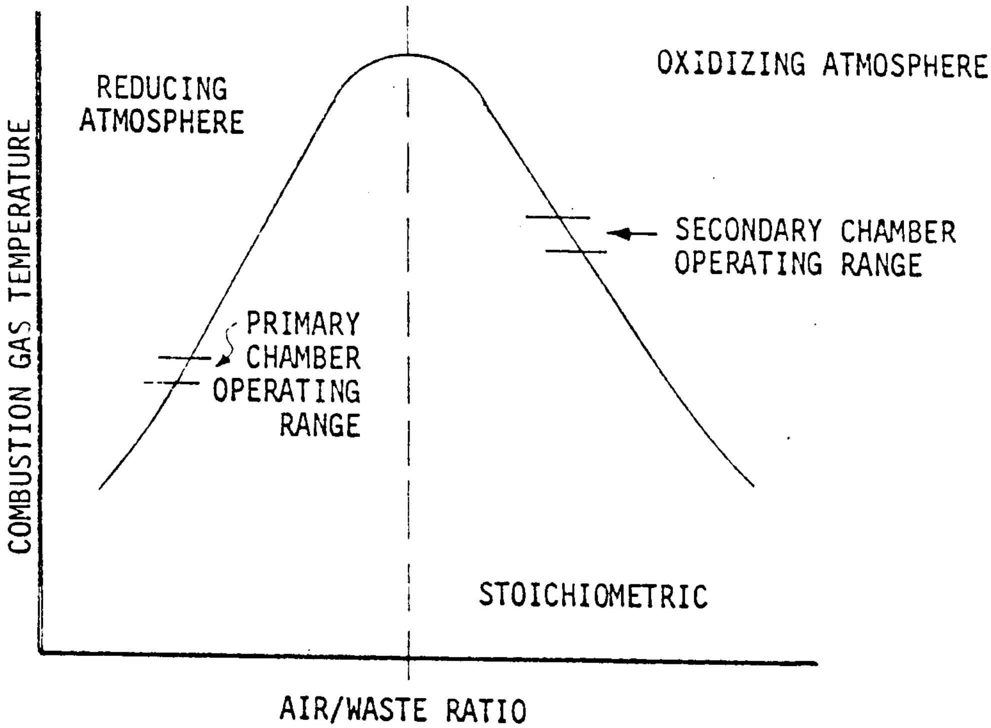


Figure 5.2. Schematic of design temperature operating range.

incinerators.[16] One was at the Truck Axle Division of Rockwell International Corporation in Marysville, Ohio and the other in the Municipal North Shore Energy Plant in North Little Rock, Arkansas.

A.2.2 Feeding mechanism

The waste to be burned is batch fed into the primary chamber at prescribed intervals. The waste stream usually need not be pre-processed even with municipal wastes before it enters the primary chamber. The feed rate is usually dictated by the temperature in the secondary chamber. Overfeeding causes high temperature in the secondary chamber, excessive gaseous emissions, and wasted energy. Underfeeding reduces throughput and lowers the combustion chamber temperatures requiring auxiliary fuel. Proper feed rate is essential.[17]

A.2.3 Primary chamber

During start-up, auxiliary burners dry, volatize, and ignite the waste. When the combusion rate is sufficient to sustain partial oxidation, the auxiliary burners are shut off. The combustible gases and particulates generated in the primary chamber, flow into the secondary chamber, where combustion is completed. The combustion in the primary chamber is sustained sufficiently to keep the auxiliary burners use to a minimum in some models, and yet still burn both the gas by-products and the combustible solids of subsequent waste batches.

A.2.4 Secondary chamber

The secondary chamber is initially heated by an auxiliary burner. The auxiliary burner ignites the partially oxidized combustibles flowing from the primary chamber. The combustion generating heat eventually becomes self-sustaining. The burner automatically is shut off by a temperature control device and remains off while the unit maintains 760° to 888°C (1400° to 1600°F). The temperature is sensed by thermocouples with set points. When the chamber temperature reaches the set points, the thermocouples activate controllers which modulate airflow dampers and turn the burner on and off.

A.2.5 Heat recovery boiler

Water or fire tube boilers recover the thermal energy from the flue gases exiting the secondary chamber. The fire tube boiler requires: (1) clean exhaust gas stream, less than .15 grain/foot^3, (2) pressure recovery conditions less than 250 psi, (3) output less than 15,000 lbs/hour. Watertube boilers are preferable because: (1) better for heavily laden particulate matter in the flue gases, (2) high attainable pressures, (3) less damage in case of explosion, (4) easier to keep clean.

A.2.6 Operation

These modular incinerators which are batch fed have five modes of operation: Warm-up, charging, burn down, cooling and clean out. The warm-up period requires about 1/3 to 1/2 hour to heat up the secondary chamber so that when the gaseous products begin to arrive they can be easily combusted.

Charging is usually signaled by a red light. This is based on the incinerator heat sensing controls, approximately six to eight times per hour. The waste is usually delivered onto the tipping floor by refuse collection trucks and dumped into piles adjacent to the loading platform. The normal operation is for a tractor operator, using a small front-end loader, to scoop a full load of waste from a pile and release it onto the loading platform. When the pile on the platform is roughly the required weight, the tractor operator energizes a switch to open the door of the charging box. Then pushes the entire load off the end of the loading platform, which drops it into the charging box. As the operator backs off the platform, he energizes a second switch that closes the charging box door, opens the guillotine door on the incinerator and activates the hydrolic ram mechanism. An occasional jam may be corrected by the operator with a stop pushbutton. The ram returns to a point just clear of the guillotine door and the guillotine door closes. On some charging boxes, water sprays hit the ram face. This clears off any material which may have adhered. Precautions are taken to prevent any burning inside the hopper. The ram then moves to its full rear position, ready to accept another waste charge and begin the cycle over again.

The modular incinerators that are not equipped with automatic ash removal are usually charged from seven to ten hours per day. The required burn down period requires about three hours. The secondary burners are left on at low fire levels during this period, completely combusting the gaseous products slowly being released from the primary chamber. After the shutdown cycle the incinerator is allowed to cool down until the next morning.

The ash removal takes place as soon as the operator arrives in the morning. The procedure with those incinerators without automatic ash removal, involves the operator using the loading tractor with a long ash "rake" attached to the front end. The ash is either dumped directly into ash carts or onto the platform in front of the incinerator. After the module has been emptied, it is ready for the day's combustion operation.

A.2.7 Maintenance

The tipping floor is kept clean by hosing and sweeping at the end of the day. Additional routine maintenance consists mainly of small refractory repairs and replacement of thermocouple switches, door seals, and motors. The waste type being burned dictates the frequency of soot removal from the boiler tubes and cleaning of the induced draft fan blades. The frequency varies from once a week when burning municipal waste, to twice every year while burning industrial waste, consisting primarily of wood and paper.

The major maintenance requirement is the refractory replacement every 3 to 8 years, depending on the usage and waste type. The amount of major maintenance and operational interruptions are most strongly a function of the amount of glass and metals found in the waste stream. Clear glass melts at 1840°F forming clinkers when solidified. Slag formed from the fusion of glass and metals frequently plugs air injection ports and erodes and corrodes the refractory.

Another potential maintenance problem occurs in the boiler from corrosion and erosion of the boiler tubes. Corrosion from localized reducing atmosphere is probably minimal due to the compact geometry and intimate mixing of excess air and combustion gases within the incinerator.[20] Nevertheless, corrosion caused by the combustion of chlorine products can be a problem. The largest source of chlorine tends to be "PVC" heavy gauge plastics. The combustion of only wood and paper should never cause corrosion problems in incinerators. However, common firing of Cl-containing materials, along with large amounts of wood and paper, becomes dangerous in respect to corrosion problems.[18]

A.2.8 Refuse reduction

Refuse reduction is mostly a function of waste type. Test data on existing modular incinerators burning municipal waste report weight reductions from 55% to 70% and volume reductions between 85% to 93%.[19,20] Reported data on a modular incinerator burning primarily paper and wood waste, suggest weight and volume reductions approaching 95%.

A.2.9 Auxiliary energy needs

An important consideration in the selection of a refuse modular incinerator to replace fossil fuel, resides in the auxilary fuel requirements for start up, burn down and maintenance of steady state conditions during normal heat recovery operation. Compared to large scale incinerators, the use of auxiliary fuel in the smaller machines can create a cost problem. If the combustion engineering has not been done efficiently, large quantities of fossil fuels could be burned to achieve the desired air emission rates.

To recover refuse energy in an environmentally acceptable manner, by modular incineration, auxiliary fuel must be available. The steady state efficiency of small refractory lined incinerators, range from 50 to 65%. One manufacturer produces a water-walled modular incinerator and reports 70% efficiency. The energy input comes from both the refuse and the auxiliary fuel. To obtain a better feeling for auxiliary fuel demands of the modular incinerator, the Incinerator Coefficient of Performance (ICOP) is introduced.

$$ICOP = \frac{WHEAT,}{AUXFUEL,}$$

where:

$$1 < ICOP < 25$$

WHEAT = annual average energy recovered in the heat recovery boiler (BTU/ton)

AUXFUEL = annual average input auxiliary energy (BTU/ton)

The ICOP is dependent on a variety of variables: The refuse quality, refuse moisture content, firing schedule, steam demand, incinerator controls and average/design feed rate. This term can only be used for a seasonal performance factor and is valid between 1 and 25.

Table 5.1 shows measured ICOP for three modular incinerator installations reported in EPA documents.[21,22] The first two installations reported in Table 5.1 burn municipal solid waste. Both units were operating at relatively high average/to design feed rate ratios. The recovered steam is sold to industrial customers, who purchase essentially all of the energy recovered from the incineration process.

Table 5.1. Actual measured incinerator coefficients of performance

Name, Ref.	Waste	10^6 Btu/ton		
		Wheat	AUXFUL	ICOP
North Little Rock 22	MSW	5.16	.442	11.8
Siloam Springs 21	MSW	6.094	.440	13.85
Marysville 22	Wood and paper	4.55	3.3	1.38

The last installation listed in Table 5.1, operated at only 63% of the design feed rate. The recovered heat is used by a truck axle manufacturer to heat and cool their plant. The refuse product is made up entirely of wood and paper waste. The incinerator design meets both the plant's peak heating and cooling demands. Since the space heating and cooling load fluctuates throughout the year, much of the available recoverable energy cannot be utilized. The incinerator continues to call for some auxiliary fuel to completely burn the refuse, even when the heat is not needed.

Other energy sources are needed to operate modular incinerator facilities: Gasoline to run the small loading vehicle, electricity to run the fans, lights, pumps and motors and additional energy is needed to heat and possibly cool additional buildings, required to house the incinerator operation.

A total energy balance of the North Little Rock facility illustrates that by taking into account all auxiliary energy requirements for modular incineration, the ICOP is reduced. Table 5.2 shows the BTU equivalent per ton for all the auxiliary energy needs of the North Little Rock facility, which burns about 70 tons/day, five days per week. WHEAT increases from $.442 \times 10^6$ BTU to $.915 \times 10^6$ BTU/ton.

The ICOP is reduced from 11.8 to 5.6. The BTU equivalent for electricity was determined by using a generation and distribution efficiency of 30%. Without including electricity in the energy balance, the ICOP increases to 9.4, which would be more representative of the "scarce fuel" energy balance.

Table 5.2. Total auxiliary energy needs for the North Little Rock facility (10^6 Btu/ton refuse)

Auxiliary fuel natural gas	.442
Gasoline	.042
Fuel oil	.055
Electricity generation and distribution	.375
Total	.915

The above reported ICOPs are based on actual measured performance of commercial modular incinerators. The two facilities reported at North Little Rock, Arkansas and Marysville, Ohio were not operating at optimum conditions when they were monitored. If the North Little Rock facility had operated with a feed rate equal to the design capacity of 4 tons instead of 3.16 tons per hour, an ICOP of 16.1 would be obtainable, up from the 11.8 reported in Table 5.1. Taking into account the entire auxiliary energy flow, as shown in Table 5.2, the ICOP equals 7.5 compared to actual 5.6. Without including electricity in the energy balance, the ICOP increases to 12.5 compared to the actual 9.4.

If the Marysville facility had operated under optimum conditions, that is, with the feed rate and energy recovery equal to the design capacities of 1,200 pounds and 5.85×10^6 BTU, respectively, the ICOP would equal 6.95 instead of the 1.38 reported in Table 5.1.

Two important lessons can be learned from reviewing the energy balances of existing modular incinerator facilities. The first is that the unit should operate at design feed rate for as many hours as possible. Secondly, if the energy load fluctuates the amount of coincident energy supply should be examined closely to determine if the ICOP will drop below acceptable levels.

A.2.10 Environmental evaluation

Federal and state emissions limitations should be reviewed to determine whether the proposed modular incineration project will comply. However, "state reviews of, and actions regarding, new waste-to-energy projects, as mandated under plans being implemented for the attainment and preservation of ambient air quality, may affect the acceptance of a new source in a given area even if it complies with applicable emissions limitations."

A.2.11 Federal law standard for particulate matter

Federal law standard for particulate matter (121:1526 60.52), pertains to facilities burning more than 45 metric tons per day (50 tons/day).

"No owner or operator shall cause to be discharged into the atmosphere any gases which contain particulate matter in excess of 0.18 gr/dscm (0.08 gr/dscf) corrected to 12% CO_2."

The Clean Air Act Amendments of 1977 require that the Administrator of the EPA review and, if appropriate, revise established standards of performance for new stationary sources at least every four years. The November 27, 1979, Federal Register announced EPA's intent to investigate the establishment of a revised standard, beginning in FY 1980. There was no mention of any change in the standard pertaining to the coverage of units below 50 tons per day.

The EPA announcement suggests that the particulate standard will be lowered from 0.08 gr/dscf to something like (0.06 gr/dscf), which has been attained in a number of large incinerators equipped with electrostatic precipitators.

A.2.12 Tennessee state law

Tennessee state law (Environmental Reporter — State Air Laws, pp. 10-12, Chapter 1200-3-5 — Visible Emission) states, "No person shall cause, suffer, allow or permit discharge of a visible emission from any air contaminant source with a density greater than number one (1) of the Ringelmann Chart or an opacity of excess of twenty (20) percent for an aggregate of more than five (5) minutes in any one (1) hour or more than twenty (20) minutes in any twenty-four (24) hour period."

Every state has an opacity standard for new incinerators of 20% or stricter, except Illinois (30%), Indiana (40%), and Delaware (no standard).

The maximum allowable particulate emission from incinerators is 0.2000% of the charging rate for incinerators with a 2,000 pound per hour charging rate or less and 0.100% of the charging rate for incinerators with a charging rate greater than 2,000 pounds per hour.

An opacity standard may be established consistent with EPA policy, such a standard would not be more restrictive than the particulate mass standard.

A third regulation which all federal facilities must comply with is incineration of under 200 lb/hour – 0.3 gr/SCFD @ 12% CO_2; equal or over incineration of 200 lb/hr – 0.2 gr/SCFD @ 12% CO_2 (3.77 lb/ton of refuse).

A.2.13 Particulate emissions

Today there is no federal particulate emission standard for incinerators burning less than 50 tons per day. However, most states have some restrictions on small incinerators, and it is conceivable that tighter emission standards could be levied on small incinerators in the future.

The primary reason the starved air modular incinerators are cost effective is due to the absence of any expensive exhaust gas treatment equipment. For high efficiency wet scrubbers in the size range of 25-50 tons per day the total installed cost would be about $65,000 (1980 dollars) and for an electrostatic precipitator, $158,760 (1980 dollars). The installed cost of an incinerator capable of burning 1300 lbs/hour is about $200,000. A wet scrubber would increase the installed incinerator cost 33% and if an electrostatic precipitator should be needed, the capital cost of the incinerator would increase 80%.

The Tennessee State Law state states that for every ton of refuse burned, the maximum allowable emission rate is 4 lbs per ton. The refuse incineration emission factors from the Environmental Protection Agency AP-42 display 1.4 lb/ton for controlled air incinerators.

Table 5.3 shows a variety of reported particulate emission rates taken from commercially operating facilities. Most of the test results displayed in Table 5.3 were obtained from incinerators burning municipal solid waste, which is considerably more heterogenous than institutional wastes, made up largely of paper. The more heterogeneous the fuel type, the more difficult it is to sustain steady state operating conditions, during combustion,which reduces emissions. USPHS test waste used in the Kelly Incinerator Test is defined in Table 5.4.

Some controlled-air incinerators have only a single combustion chamber. Others are built with a second combustion chamber, usually

Table 5.3. Particulate emission test results

Name	Maximum	Average (lb/ton)	Minimum	Waste	Heat Recovery	Reference
North Little Rock	3.03	1.7	.88	MSW	Yes	Frounfelker
Marysville	2.01	.9	.6	68% wood 32% paper	Yes	Frounfelker
Pahohee, Florida	2.0	1.7	1.5	MSW	No	Hofmann
Orlando, Florida	2.4	1.8	1.2	MSW	No	Hoffmann
Siloam Springs	1.3	1.0	.75	MSW	Yes	Hoffmann
Kelly Company Plant		.65		USPHS test waste	No	23

Table 5.4 USPHS test charge

Material	Percent by Weight
Corrugated cardboard shredded into 1/2-inch strips	23
Newspaper cut into strips 2 by 12 inches	22
Magazines cut along bindings into pieces 2 by 12 inches	17
Brown paper, wax-coated or impregnated paper, and plastic-coated paper, equal portions of each, in pieces no larger than 6 x 6 inches	15
Raw potatoes cut into slices approximately 1/2 by 1/2 by 3 inches	23
	100

of approximately equal size, and above the primary combustion chamber. This secondary combustion chamber provides the flue gases with sufficient residence time for complete burnout of the volatile gases and airborne organic particulates. The minimum residence time should be 0.5 seconds, with 0.7 seconds recommended to provide a safety margin.

If sufficient residence time is not allowed, flames, in the burning flue gases exhausted from the incinerator, will carry over into the breeching and into the waste-heat boiler. Damage to these components and loss of thermal efficiency is inevitable.

The controlled air incinerators are capable of emitting relatively low particulate levels for three reasons: Time, temperature and turbulence. In the primary combustion chamber, the air flow is minimal, offering little force to carry particulates up the flue. The secondary combustion chamber adds temperature and turbulence to the flue gases. The large volume in the secondary chamber also adds to the retention time of the flue gases allowing them more time to combust.

A.2.14 Trace metals

Among the elements supplied in substantial quantities by incinerators, cadmium, antimony and lead are known to be toxic.[24]

The amounts of trace elements released is a function of the refuse contents. Table 5.5 shows the detected amounts of known toxic elements in North Little Rock and Marysville facilities.

Table 5.5. Toxic trace metals emissions

	lb/ton (ug/m³)		
	Lead	Cadmium	Antimony
North Little Rock	.142437 (4,493.98)	.004089 (129)	.000441 (13.42)
Marysville	.015518 (624.17)	.010631 (427.62)	.000042 (1.69)

Cadmium, chromium, lead, manganese, silver, tin and zinc apparently come from the noncombustible components of refuse as well as from the combustibles. The removal of the noncombustible components of refuse by some recycling operation, prior to use of the remainder for fuel, will reduce concentrations of these seven metals. Also, concentrations of antimony, cobalt, mercury and nickel may be reduced by separating the combustibles from the noncombustibles, prior to burning. A further reduction of cadmium, copper and other heavy metals possibly can be produced by not including heavy-gauge plastics.

Trace metals are currently not included in any incinerator emission limitations. However, detrimental health effects are enhanced because these elements are predominantly associated with small respirable particles. Much of the material is soluble in water and dilute acids. Thus, the particles can be deposited deeply in the lungs where the toxic elements can be dissolved in body fluids and mobilized.

In the North Little Rock Plant, 95%, by weight, of the particulate were smaller than 7um, and 50%, by weight, were 0.3um or less. In the Marysville tests, 85% by weight, of the particulates were smaller than 7um.

A.2.15 Opacity tests

Opacity is a second emission standard found in most state air pollution codes. Table 5.6 shows a number of opacity recordings made on a variety of modular incinerators.

The maximum opacity readings, found in the test results from Marysville and North Little Rock, appears to be a cause for concern.

Table 5.6 Opacity test results

Name	Opacity (%) Max.	Avg.	Min.	Heat Recovery
North Little Rock, Arkansas	42	24	12	Yes
Marysville, Ohio	42	--	15	Yes
Pahokee, Florida	20	Not available		No
Orlando, Florida	10	"		No
Siloam Springs	10	"		Yes

The last three units easily fall below the 20% opacity level. Discussions with a number of modular incinerator owner operators indicates that the exhaust is not visible from the stacks after the initial start-up period of 20 minutes. According to the EPA report " Evaluation of Small Modular Incinerators in Municipal Plants," visible emissions were infrequent.

Previous experience has shown that short periods of visible emissions from controlled air incinerators can be accounted for by disturbances in combustion air feed. These, in turn, can be caused by air controls, loader jams, explosions of the waste and lag time in sensing and controlling systems. If operated properly, opacity requirements will not be a problem. Overfiring and underfiring must be avoided at all times.

A.2.16 Acid gases

Currently, acid gases such as hydrogen, chloride and hydrogen fluoride are not regulated. Theoretically in most institutional waste streams with low plastic percentages, neither acid gas will present problems. However, if a lot of plastics are in the waste stream, HCl and HF emissions should be watched. These gases also contribute to the corrosion of boiler tubes. Acid gas emissions from various industries, when regulated, generally are restricted to the range of 5 ppm. In Little Rock, the concentrations of chloride ranged from 13 to 420 ppm (19 to 610 mg/m^3) and averaged 130 ppm (187 mg/m^3). Those of fluoride range from 0.6 to 5.5 ppm (0.5 to 4.3 mg/m^3) and averaged 2.0 ppm (1.6 mg/m^3). In Marysville the concentrations of chloride ranged from 3 to 94 ppm (4 to 136 mg/m^3) and averaged 26 ppm (38 mg/m^3), while those of fluoride ranged from 0.3 to 2.6 ppm (0.2 to 2.0 mg/m^3) and averaged 1.1 ppm (0.9 mg/m^3).

A.2.17 Manufacturers and installations

Presently, there are 16 manufacturers producing very small modular incinerators. A total of 92 modular incinerators were found in industry with waste heat recovery. More than half of the modular incinerators with waste heat recovery have been installed by the Kelley Company. A list of manufacturers of modular incinerators is shown in Table 5.7 and their addresses in Table 5.8.

In a literature survey, I found reference to 15 modular incineration installations. Table 5.9 lists the location, brief description and reference for each installation.

Table 5.7. Manufacturers of modular incinerators

Manufacturer	Incinerator type: Municipal no. With heat recovery	Municipal no. Without heat recovery	Industrial no. With heat recovery	Industrial no. Without heat recovery	Air emissions control equipment normally employed	Combustion process	Capacity range Mg/day (TPD)
Basic	0	0	6	6		#	33 (36) to 136 (150)
Burn-Zol	0	0	1	0	X	†	up to 22 (24)
C. E. Bartlett	0	0	0	19	X	#	up to 35 (38)
Clear Air	0	3	0	0	X	#	44 (48) to 272 (300)
Comtro	0	3	3	N		†	up to 22 (24)
Consumat	4	13	4	N	X	†	up to 45 (50)
Econotherm	0	0	4	N		†	up to 29 (32)
ECP	1	0	14	N		†	up to 43 (48)
Giery	1	0	0	0	X	#	22 (24) to 65 (72)
Kelley	0	6	49	N		†	up to 22 (24)
Lamb-Cargate	0	0	2	0		†	up to 181 (200)
Morse-Boulger	0	4	1	0	X	#	up to 227 (250)
SEE	0	1	0	0	X	†	up to 136 (150)
Simonds	0	0	7	N		#	up to 27 (30)
Smokatrol	0	0	1	N		†	up to 37 (30)
Washburn	1	1	0	0	X	†	up to 22 (24)

Excess air incineration.

† Starved air incineration.

N Numerous.

Table 5.3. Addresses and telephone numbers of modular incinerator manufacturers

Basic Environmental Engineering, Inc. 21W161 Hill Glen Ellyn, Illinois 60137 (312) 469-5340	Giery Company, Inc. P.O. Box 17335 Milwaukee, Wisconsin 53217 (414) 351-0740
Burn-Zol P.O. Box 109 Dover, New Jersey 07801 (201) 361-5900	International Waste Industries South Adams and Queens Streets Pottstown, Pennsylvania 49464 (215) 323-2200
C. E. Bartlett-Snow 200 West Monroe Chicago, Illinois 60606 (312) 236-4044	Kelley Company, Inc. 6720 N. Teutonia Avenue Milwaukee, Wisconsin 53209 (414) 352-1000
Clear Air, Inc. P.O. Box 111 Ogden, Utah 84402 (801) 399-9828	Lamb-Cargate P.O. Box 440 1135 Queens Avenue New Westminster, British Columbia V3L 4Y7 (604) 521-8821
Comtro Division 180 Mercer Street Meadville, Pennsylvania 16335 (814) 724-1456	Morse-Boulger 53-09 97th Place Corona, New York 11368 (212) 699-5000
Consumat P.O. Box 9574 Richmond, Virginia 23228 (804) 746-4120	Progressive Equipment Company, Inc. 1330 Blue Hills Avenue Bloomfield, Connecticut 06002 (203) 242-0721
Econo-Therm 1132 K-Tel Drive Minnetonka, Minnesota 55343 (612) 938-3100	Scientific Energy Engineering, Inc. 1103 Blackstone Building Jacksonville, Florida 32202 (904) 632-2102
Environmental Control Products P.O. Box 15753 Charlotte, North Carolina 28210 (704) 588-1620	Simonds Company P.O. Drawer 32 Winter Haven, Florida 33880 (813) 293-2171
Environmental Services Corporation P.O. Box 765 Crossville, Tennessee 38555 (615) 484-7673	U.S. Smelting Furnace Company (Smokatrol) P.O. Box 217 Belleville, Illinois 62222 (618) 233-0129
Federal Enterprises Springfield, Missouri	Washburn and Granger 85 5th Avenue Patterson, New Jersey (201) 274-2522
Surface Combustion Toledo, Ohio	

Table 5.9. Modular incinerator installations with heat recovery

Location	TPD	Incinerator Manufacturer	Waste Burned	Reference
Crossville, Tn.	60	ESCOR	MSW	Field trip, Nelson Walker
Johnson City		Consumat	Hospital Waste	Dick Piske, I. C. Thompson
St. Louis GM	120	N.A.	Industrial	27
Durham, N.H.	105	Unknown	MSW	28
Salem, Va.				28
Sheboygan, Wis.	12	Kelley	Industrial	29
Jacksonville, Fla.	40	Unknown	MSW	30
Siloam Springs, Arkansas	21	Consumat	MSW	31
Little Rock, Arkansas	70	Consumat	MSW	32
Pentagon Wash. D.C.			Institutional	
Blytheville, Arkansas	50			
Groveton, N.H.	30		MSW	
Marysville	12	Kelley	Industrial Wood and paper	32
Clarksville, Tn.		ECP	Industrial plant waste	Nelson Walker
Memphis, Tn.	20	George L. Simonds	Type 0	54

A.3 RDF co-fired in an existing on site boiler

Refuse derived fuel is defined as refuse which has undergone a degree of pre-processing in an attempt to remove the non-combustibles and obtain a fuel which is more homogenous than the "as received" solid waste.

Section 8002 (d) of the Resource Recovery and Conservation Act of 1976 (RCRA) required the U.S. Environmental Protection Agency (EPA) to conduct a study of small-scale and low technology resource recovery. The report prepared by SCS Engineers, "Small-Scale and Low Technology Resource Recovery Study" concluded that RDF requires: (1) sophisticated mechanical equipment and skilled, trained operators, (2) has only adequate reliability and (3) the products have limited marketability and prices are subject to cyclical swings, therefore RDF is not applicable to refuse generators with less than 100 tons per day. However, SCS engineers seem to be assuming that the waste generator cannot utilize all of the RDF internally.

There are three basic types of RDF which can be produced: fluff, dust and densified. The production of these three types varies, as do the burn characteristics.

The basic system for production of fluff RDF involves: (1) shredding, (2) separation of the combustible and non-combustible fraction of waste by air classification and (3) secondary shredding. The production of dust or densified RDF requires additional steps. Both dust and densified RDF have a lack of commercial scale-experience The three RDF systems in operation (Ames, Iowa – 200 TPD, Chicago, Illinois – 1000 TPD and Milwaukee, Wisconsin – 1,600 TPD) produce fluff RDF.

RDF users must modify storage, handling and combustion practices to burn the material in existing boilers. RDF, even after efficient processing, is a heterogeneous substance. "Bridging and arching" the formation of self-supporting masses of material that will not move as planned through the storage system, continue to plague many RDF systems.

Another consideration when burning refuse as a supplementary fuel is that boilers with capacities of less than 100,000 pounds steam/hour, may be marginal for burning refuse due to their small furnace volume. Generally, it takes more time and consequently, more furnace volume to burn refuse than coal.[33] Another reason the smaller units may be marginal, is because the high first cost of the refuse preprocessing equipment.

The allowable gas velocities in the convection passes of coal fired boilers are generally much lower on municipal refuse. This means that the use of refuse as a supplementary fuel requires derating the unit output capacity. Another factor to consider is, the fan requirement. More air is required to burn refuse than coal. Therefore, the capacity of the existing fans would have to be carefully scrutinized.

A.3.1 Advantages

The separation of the combustible materials from the noncombustibles before incineration results in a reduction of trace metal emissions.[34] Burning refuse with coal is reported to reduce SO_2. The higher alkali metal content of the RDF causes more of the sulfur to be bound up in metal sulfates, which can be precipitated. Also, RDF tends to reduce NOx because the combustion temperature is reduced.

RDF makes a heterogeneous fuel somewhat more predictable. Thus, making combustion control more feasible. Also, RDF co-fired with coal adds sulfur to the refuse, which reduces the corrosion rates of carbon steel and stainless steels significantly.[35]

A.3.2 Potential barriers

Dust formation tends to be a continuing problem during RDF processing. Workers require some type of filtering system to continue breathing satisfactorily.

The addition of the extensive amounts of movable parts and machines require considerable additional maintenance requirements. RDF is still relatively unproven and therefore, their application is associated with high technical and economic risks. Also, RDF characteristics are not suitable for long-distance transportation or long term storage.

Co-firing of RDF can decrease the efficiency of electrostatic precipitator performance at an existing coal-burning plant, cause higher excess air requirements. Merrimac in St. Louis found a precipitator performance drop from 97.5 to 95.4 a 1.6% drop.[36] The bottom ash loads have been found to increase seven fold for a 10% heating contribution from RDF.

A.4 Large incinerator with heat recovery

A.4.1 Description

This concept involves the institution connect to a district heating system which is at least, in part, heated by refuse. Only part of the refuse fed into the incinerator need be drawn from the institute itself and the heat may be sold to other customers than the institution.

An example of this refuse to district heating system is found in Nashville. The Nashville Thermal Transfer Corporation is a central heating and cooling plant. It uses about 500 tons per day of municipal solid waste as fuel in waterwall boilers. Another example is presently being studied in St. Paul, Minnesota.

Many institutions are located in the high density urban areas which are the main candidates for district heating. The high density reduces the length of distribution piping needed and thus the cost of interconnecting the buildings.

As a result of significant perceived public benefits from a co-generated, hot water district heating system in St. Paul, the St. Paul mayor's office, the Minnesota Energy Agency and the Northern States Power Company (NSP) have formed a non-profit corporation. The title of the corporation is the St. Paul District Heating Development Company, Inc. The first phase of work by this corporation is a detailed planning phase, including engineering, marketing, economic, institutional analysis and planning tasks.
The goal of this phase is to develop the design basis for initiating

a 150-200 MW hot water district heating system. This would be located in the central business district of St. Paul, Minnesota, in 1981, to be supplied by NSP's High Bridge Power Plant. More than one million dollars, from public and private sources, have been committed to this project. The heat source backbone of this system is designed to be supplied from co-generating power plants.

The addition of refuse to district heating is being studied from a reliability and flexability standpoint. There are a number of unique advantages in connecting to a district heating system with refuse as a partial heat source.

A.4.2 Advantages

Figure 5.3 shows an example of the benefits of coupling a waste-to-energy facility with a young growing district heating system. The graph in the top left corner of Figure 5.3 shows the percent of peak load (200 MW) needed across one full year of operation. The average load for the St Paul type climate is about 28%. The heat from the co-generation power plant is sized to only meet about 60% of the peak load, the remaining load is met by oil fired peaking boilers. The peaking boiler fuel usage is indicated by the shaded areas in the top of the curve. During the summer months the electrical generation capacity is required during system electric peak load periods. Thus, the thermal energy is not available from the co-generation plant. The thermal needs are then met by the back-up fossil fired boilers. The oil usage is represented by the shaded area above the time period marked 10 through 12.

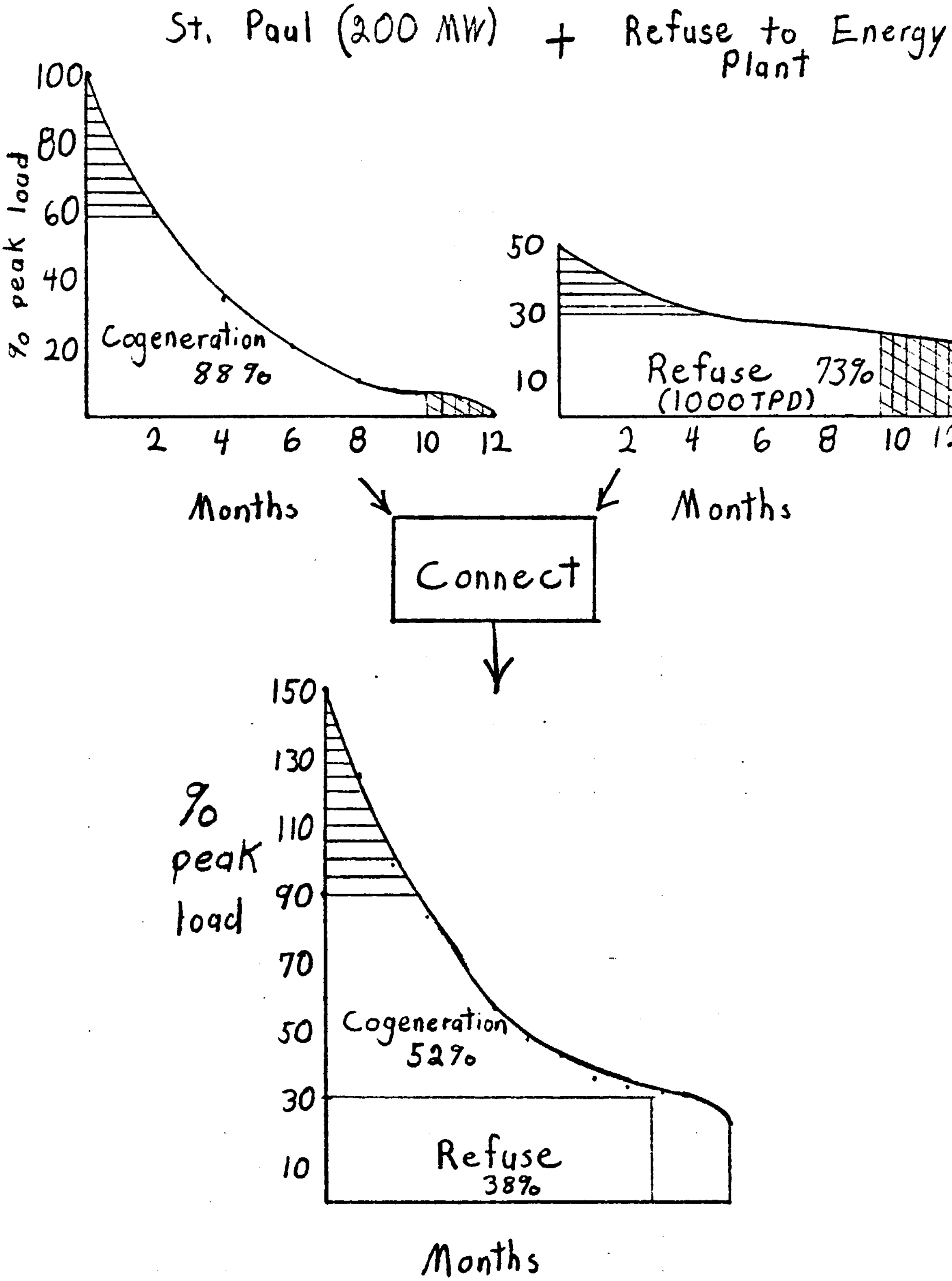


Figure 5.3. District heating connected with a waste-to-energy facility.

The top right hand curve represents a refuse-to-energy system initially serving a base or intermediate loaded thermal demand. The shaded area at the top represents peaking fossil boiler fuel needs. The shaded area above the time period marked 10-12, represents the time in which the incinerator is not available. The availability of large incinerators varies between 70 and 90%. Usually, this energy demand is made up by fossil fired backup boilers.

If these two systems were connected by a thermal conveyance line, both systems would benefit in at least four ways: First, both systems would expand their market. The refuse plant is assumed to have excess thermal energy available in the summer months that could satisfy the heat needs of the district heating system. The district heating system is backed up with fossil fired boilers. Also, the co-generation system is assumed to be able to sell thermal energy to the refuse system during periods of incinerator unavailability. Thus, expanding the co-generated thermal energy market. Secondly, more scarce fuel savings result. Thirdly, the addition of refuse-to-energy plants to a district heating system enhances overall system reliability. Finally, coupling a refuse-to-energy plant to a district heating system adds flexibility. In Sweden a district heating system tends to grow first around "growth nodes." The buildings are hooked up and the energy source is initially provided by oil fired boilers, until the main truck line is completed. With a refuse-to-energy system located near a growth node, much of the fossil fuel consumption could be displaced by burning refuse. The major problem with this example, is that the refuse-to-energy plant is likely to be serving a customer with a low load factor. Therefore some of the available thermal energy may not be utilizable.

A refuse-to-district heating system is likely to have greater public support than many waste-to-energy plants. This is because more of the community benefits, not only from environmentally sound waste disposal, but also from the energy recovered from the refuse. Most waste-to-energy facilities in the United States serve only one industrial customer. Refuse-to-district heat is more likely to show either potential profitability and/or greater redeeming social benefits, which make the project "socially," if not financially, profitable.

By selling the recovered energy to a district heating system, the market is much more dependable. If one or two customers should go out of business, go on strike or relocate, there are likely to be other customers still connected to the system, to allow continued revenue to operate the facility.

The refuse plant can provide the base thermal load of a district heating system and the intermediate load can be met by the co-generation plants. By having the co-generation plants backing up the refuse incinerators, the back-up equipment need not lie idle when not needed for thermal energy. If thermal energy demand is low, the co-generation plant can expand the steam by the low pressure turbine producing electricity to it's full potential. If a co-generation plant is capable of supplying thermal energy at a temperature level high enough for district heating (e.g. 100° C), then steam must be extracted from the power plant turbine. Therefore, there is some reduction in the power output of the turbine which reduces the quantity of electricity generated. For each unit of electric energy sacrificed, 5 to 10 units of thermal energy are available for district heating.

By selling refuse derived energy to a district heating customer, the required temperature and pressure are not too high. The lower these conditions, the less problems can be expected from boiler tube corrosion. The corrosion rates increase as the temperature of the metal tubes increase from 177-510°C (350° to 950°F).[37] The Hempstead, New York incinerators partially solved their corrosion problems by reducing operating pressure.

Another advantage for coupling a refuse-to-energy system with district heating lies in the thermal conveyance lines capability to absorb large fluctuations in feed temperature and pressure. The thermal conveyance system offers an element of thermal storage capacity.

Ideally a district heating system will eventually have a multitude of heat sources. If more than one refuse-to-energy facility can be sited, the reliability and flexibility will be increased. Another advantage, in having a few smaller plants, is that the high first cost of incinerator equipment can be spread over a few years.

If the municipality should own the district heating system and the refuse-to-energy plant, the costs are internalized. Thus, reducing risk responsibilities and uncertainties which have caused numerous proposed projects to fail before construction begins. Part of the

European's success with refuse-to-energy lies in the fact that the same entity has municipal waste disposal and district heating responsibilities.

A.4.3 Potential barriers

A.4.3.1 Environmental. Incinerators can be built which meet all existing air pollution standards. However, the areas where district heating is frequently most appealing is in the high density metropolitan areas. These are frequently classified as non-attainment.

If the non-attainment pollutants are NOx or SO_2, incinerators would likely improve the area by replacing fossil fuel combustion. If the non-attainment concern is with particulates, the case is not clear as to whether the particulate level in the air "bubble" will be reduced. In some instances, the reduction in particulate from refuse hauling offsets the increase due to the incinerator.

Examination of the composition of the particulates which do escape incinerators indicates that there may be potential problems in terms of heavy metal emissions. The solution is a reduction in the concentration of trace metals at MSW combustion plants. It can, in part, be accomplished by separation of noncombustibles.

Refuse combustion can cause an increase in chloride levels, over fossil fuel combustion, due to the high chloride content of urban waste. Air emissions of HCl from urban waste demonstration facilities have ranged widely from .1 to .5% of total waste load input. However, HCl is easier to control than SO_2 or NOx.

EPA does not have standards for chlorides or aldehydes in air or for lead in water. The lack of standards makes assessment of the impacts difficult.[38] EPA hazardous pollutant standards are being developed. Another barrier to large municipal incinerators is citizen opposition. The concern in part is: Falling property market values (without falling tax assessments), heavy truck traffic, visible pollution (such as insects, rodents, noxious odors) and the invisible dangers of exposure to unforeseen contamination and explosion hazards.

A.4.3.2 Technical. The host of technical barriers listed are actually problems, which proper design can handle. Visible smoke may be caused by lack of sufficient overfire air, insufficient overfire air jet penetration, mal-distribution of primary air and nonuniform feeding of refuse.[39] Another frequently occuring problem, is control of boiler-water quality to prevent internal scaling of the wall tubes. A very common operating difficulty in refuse incineration is corrosion of heat recovery surfaces exposed to combustion products.

A.4.3.3 Financial. Lack of regulatory initiative and enforcement, by many states, allows cheaper but environmentally unacceptable disposal practices to persist.[40] In some cases, the cost to recover energy remains greater than the recovered energy price dictated by the marketplace. The needed tipping fees remain $7-$15 per ton, to pay back the refuse-to-energy facility.

"The most significant deterrent to implementing a resource recovery project is the incredibly complex planning process."[41] Frequently, $200,000 to $500,000 is needed for the necessary planning that brings a project to its financing stage. Incinerators are large capital expenditures and they have a "locking in" effect which tends to lack flexibility.

These barriers should be recognized and dealt with directly. With careful planning and analysis, most of these barriers can be overcome or at least minimized to levels acceptable by most concerned parties. A few refuse energy plants coupled with district heating in Europe are shown in Table 5.10.

B. Waste-to-Energy Options for ORNL

B.1 Modular incinerator with heat recovery near Building 7601

B.1.1 Design and description

The Building 7601 complex is located approximately 2.5 miles from the main ORNL facility as shown by the map in Figure 3.1 (page 17). Presently, the surrounding buildings in this area are used for office space and a number of experiments. The "Building 7601" complex consists of approximately 24,500 ft^2 of office space and another 30,000 ft^2 of 50 foot high bay areas used for research experiments.

The complex currently has two oil fired heat sources, one 6,000 pound/hour boiler, which provides 140 psig steam for experimental process needs, and a second hot water heating unit which has a maximum capacity of 16,750 MBtu/hour and is used for providing space heating needs to the entire complex.

Table 5.10. Typical European steam producing incineration plants

Country Plant Location	Year of Initial Startup	Total Capacity T/day (Mg/Day)	Stoker Manufacturer	Steam per unit: Flow lb/hr x 10^3 (Mg/hr)	Steam per unit: Pressure psi (MPa)	Steam per unit: Temperature 0.8 (°C)	Air Pollution Equipment
West Germany							
Darmstadt	1967	230 (227)	Von Roll	55 (25)	665 (4.59)	840 (449)	ESP
Ludwigshafen	1967	250 (227)	Von Roll	50 (23)	585 (4.03)	805 (429)	ESP
Laverkusen	1969	270 (245)	Von Roll	62 (28)	270 (1.86)	580 (304)	ESP
Bremen	1969	330 (300)	VKW	33 (15)	340 (2.34)	420 (216)	N/A
Iserloch	1970	210 (190)	B&W	44 (20)	340 (2.34)	480 (249)	N/A
Offenbach	1970	270 (245)	VKW	57 (26)	340 (2.34)	480 (249)	N/A
Landshut	1971	220 (200)	Von Roll	15 (7)	270 (1.86)	660 (349)	N/A
East Germany							
Basel	1969	290	Von Roll	88	655	660	ESP & CYC
Austria							
Vienna	1971	400 (363)	Martin	126 (57)	440 (3.03)	55 (13)	ESP & CYC

Table 5.10. (continued)

Country Plant Location	Year of Initial Startup	Total Capacity T/day (Mg/Day)	Stoker Manufacturer	Steam per unit: Flow lb/hr x 10^3 (Mg/hr)	Steam per unit: Pressure psi (MPa)	Steam per unit: Temperature (°C)	Air Pollution Equipment
Sweden							
Stockholm	1968	130 (118)	Von Roll	Hot water	215 (1.48)	250/160 (121/71)	CYC
Umea	1970	130 (118)	Von Roll	Hot water	215 (1.48)	355/260 (179/127)	CYC
Gotenborg	1970	400 (363)	Von Roll	104	270 (1.86)	420 (216)	CYC
Maimo	1969	230 (209)	Martin	Not water	115 (0.79)	N/A	CYC
France							
Rennes	1968	130 (118)	Martin	35 (16)	370 (2.55)	440 (227)	N/A
Strasbourg	N/A	390 (354)	Von Roll	72 (33)	765 (5.28)	860 (460)	ESP
Soviet Union							
Moscow	1970	220 (200)	Martin	32 (15)	185 (1.28)	380 (193)	N/A

Table 5.10. (continued)

Country Plant Location	Year of Initial Startup	Total Capacity T/day (Mg/Day)	Stoker Manufacturer	Steam per unit Flow lb/hr x 10^3 (Mg/hr)	Steam per unit Pressure psi (MPa)	Steam per unit Temperature (°C)	Air Pollution Equipment
Italy							
Mailand	1971	270 (245)	Volund	50 (23)	440 (3.03)	825 (441)	N/A
Finland							
Helsinki	1969	90 (82)	Von Roll	35 (16)	205 (1.41)	660 (349)	N/A
Lahti	1969	130 (118)	Lokomo	26 (12)	555 (3.83)	840 (449)	N/A

The two heating units burn oil stored on site from a single storage tank. The monthly oil consumption for the last four years is shown in Table 5.11.

The exact amount of oil consumed by each boiler had not been measured. However, the large boiler used for space heating purposes is completely shut off during the summer months. The process steam boiler was installed in early 1978.

The process steam boiler has been used intermittently. Sometimes it will be used daily for an entire month. Then it will be shut off for a two week period. An estimate of the monthly oil consumption of the process steam boiler can be arrived at by taking the average monthly consumption during the 1978 and 1979 summer months. An average of 1,127 gallons per month of oil was used during the summer months.

By assuming that the estimated 1,127 gallons per month, is a representative average for all months of the year, the demand for space heating needs shown in Table 5.12 can be arrived at by subtracting 1,127 gallons from each month's oil consumption value.

The annual average oil consumption for the Building 7601 complex including both boiler's usage equals 56,129 gallons. This converts to a BTU load of 5422×10^6 assuming a boiler efficiency of 70%.

The annual oil demand by the space heating boiler equals 39,664 gallons. This converts to a BTU load of 3832×10^6.

The future energy demand looks considerably different from the past four years. Presently, extensive construction is taking place which involves raising the roof on one of the bay areas and setting up three experimental fuel reprocessing loops. The fuel reprocessing

Table 5.11. Oil consumption at the Building 7601 complex for space heating and process steam (gallons)

Month	1976	1977	1978	1979	Average
June	0	0	712	1,956	1,690
July	0	0	1,357	700	1,029
August	0	0	631	1,703	1,167
September	200	0	750	1,206	978
October	3,046	3,180	5,951	4,591	5,271
November	6,226	5,412	6,592	6,831	6,712
December	8,000	10,343	7,531	11,000	8,937
January	5,500	9,674	9,450		9,562
February	4,760	7,152	7,739		7,446
March	4,556	4,328	8,156		6,242
April	2,567	3,950	5,652		4,801
May	424	2,300	2,288		2,294
Total	35,279	46,339	56,809		56,129

Table 5.12. Oil consumption at the Building 7601 complex for space heating only (gallons)

Month	1976	1977	1978	1979	Average
June			0		
July			0		
August			0		
September			0		
October	3,046	3,180	4,824	3.464	3,629
November	6,226	5,412	5,465	5,904	5,702
December	8,000	9,216	6,404		7,873
January	5,500	8,574	8,323		7,457
February	4,760	6,025	6,612		5,799
March	4,556	3,201	7,029		4,929
April	2,567	2,823	4,525		3,305
May	424	1,173	1,161		920
Total	35,279	39,577	44,343		39,664

experiments require steam to evaporate certain products. These experiments will be coming on line in early 1982. The average steam demand will increase to 5,000 pounds per hour.[42] The peak demands are estimated to be 10,000 pounds per hour, which exceeds the present available process boiler capacity. At first, the experiments will be run for shorter periods of time. Eventually a continuous 24 hour a day, 7 day per week steam demand should be anticipated. The present thinking on how to meet additional capacity is not to depend on oil. The inclination is towards an electrode boiler. A 5,000 pound per hour steam demand for 8,760 hours a year converts to an energy demand $35{,}040 \times 10^6$ BTU at a 0.8 boiler efficiency. In other words, the process steam load will be increasing by a factor of 20.

A number of energy conserving projects are currently underway at the Building 7601 complex. The once-through-fan coil units are currently being modified to recirculate the internal building air. A second alteration to these buildings is that at night the fans are automatically turned off. Another consideration, which will reduce the space heating demands, is the increased heat contribution from the processing equipment. The results of these building operational changes reduce the space heating demands by about 15%.[42]

The predicted monthly energy demand, not accounting for boiler losses, is shown in Table 5.13. The total annual energy demand is $42{,}140 \times 10^6$ BTU. This represents an expected energy demand increase by a factor of almost 8 above the 1979 energy demands at the Building 7601 complex.

Table 5.13. Future energy demand at Building 7601

Month	Future Average Space Heating Demand 10^6 Btu	Average Process	Total
June	0	3,247	3,247
July	0	3,247	3,247
August	0	3,247	3,247
September	0	3,247	3,247
October	298	3,247	3,545
November	468	3,247	3,715
December	646	3,247	3,893
January	612	3,247	3,859
February	476	3,247	3,723
March	405	3,247	3,652
April	271	3,247	3,518
May	0	3,247	3,247
Total	3,176	38,964	42,140

The future monthly energy demand curve for the Building 7601 complex is just about flat as shown in Figure 5.4, compared to the present monthly demand curve.

Incinerators with heat recovery are base loaded. Refuse is produced continuously winter and summer. The energy available can only generate revenue when there is demand. Figure 5.4 shows the monthly energy demand as a percentage of the peak month for the present and future energy demands.

The future annual refuse available for incineration at ORNL is 1,650 tons. Assuming, 6,500 BTU/pound and an incinerator efficiency of 60%, results in an annual energy availability of about $13{,}000 \times 10^6$ or about 30% of the total estimated demand.

With the base hourly energy demand of 5×10^6 BTU, 1,300 pounds per hour is suggested feed rate. All of the 5 to 6 tons of refuse generated at ORNL per day can be disposed of in a single 8-10 hour shift.

If 1,300 pounds per hour of refuse is burned, approximately 4.6×10^6 BTU/hour will be transferred to either the process steam loop or building space heating hot water.

B.1.1.1 Heat exchanger. The steam line from the incinerator heat recovery boiler could feed directly into the building process steam supply line. However, a steam-to-water heat exchanger will be needed to transfer the steam energy to the hot water used to heat the building. If we assume that the present hot water system conditions of 300°F supply, 240°F return can be reduced to 180°F supply and 140°F

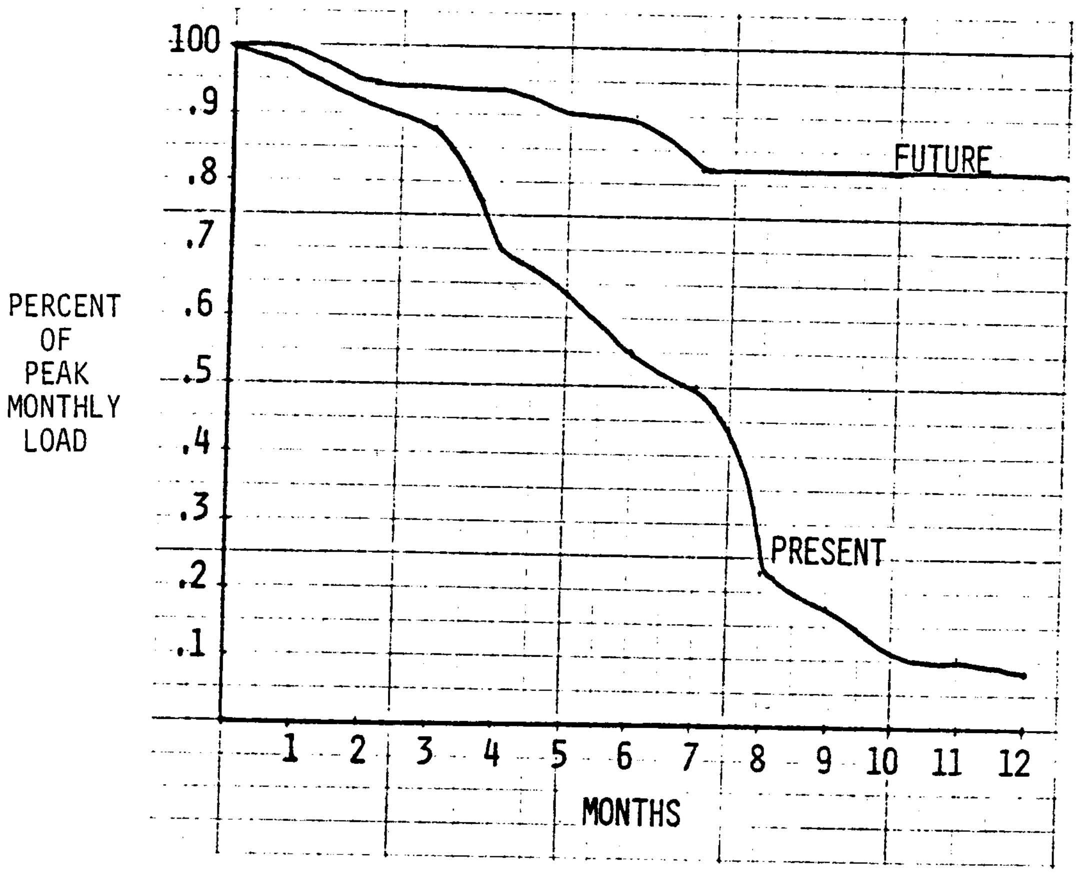


Figure 5.4. Percent of peak monthly energy demand for a one-year period.

return, the logarithmic mean over-all temperature difference between the condensing steam at 212°F would be 52°F. Equation (5.1) can be used to determine the heat exchanger surface area required.

$$A = \frac{q}{U \times LMTD} \tag{5.1}$$

where:

q = rate of heat flow (4.6×10^6 BTU)

U = overall heat transfer coefficient (500 BTU/hr)

LMTD = logarithmic mean temperature difference (52°F)

Substituting the design heat rate, overall heat transfer coefficient and the LMTD results in a heat exchanger with 177 ft^2 of heat transfer area.

B.1.1.2 Steam line. The incinerator building is located about 250 feet away from the space heating boiler and about 350 feet from the process steam boiler. Figure 5.5 shows the thermal conveyance system proposed to transfer the steam from the incinerator building to the two existing boiler rooms.

The steam line first passes by the space heating boiler room where the steam is bled off for heating up the space conditioning water in a steam-to-water heat exchanger. The steam line continues to the process steam boiler, where steam is used to meet process needs.

The steam pipe size is determined by using Equation (5.2).

$$d^2 = 0.0509\ w\ \bar{v}/v \tag{5.2}$$

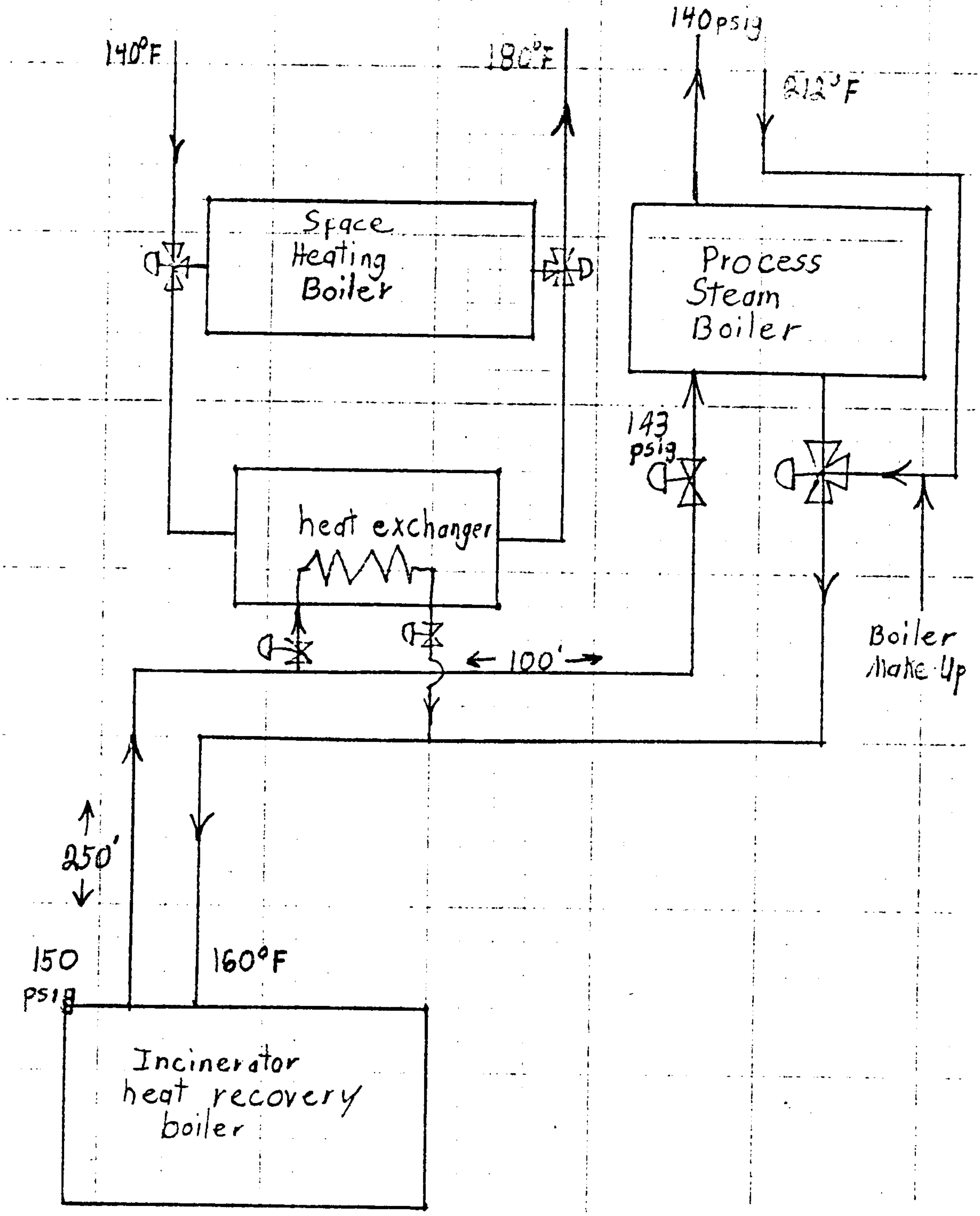


Figure 5.5. Incinerator thermal conveyance system proposed for the Building 7601 complex.

where:

d = internal diameter of pipe, in.

v = Mean design velocity over the cross section of the pipe

w = flowrate, lb/hr

$\bar{v}$ = specific volume of fluid, ft^3/lb

0.0509 = factor containing all constants

Recommended maximum steam flow velocities are around 200 feet/second.[43] By trial and error, the diameter of 3 inches was decided upon. First, the approximate size was obtained by plugging into Equation (5.2), v = 200 feet/second. This resulted in a diameter of 2 inches. This size allows for little future growth in steam rate. Thus, the next standard size pipe of 2.5 inches was used in Equation (5.2). This size results in an initial velocity of 128 feet/second.

To analyze the maximum energy delivery for selected initial steam conditions, several assumptions must be made pertaining to pressure drops, steam expansion and/or the flow characteristics through the pipe. The simplified Darcy formula is sufficiently accurate for short distance to predict pressure drop;

$$\frac{\Delta\phi}{e} = w^2 \times 10^{-6} \quad \frac{3360\ f}{d^5} \quad \bar{v} \tag{5.3}$$

where:

$\Delta\phi$ = Steam pressure drop

e = Equivalent length in 1,000 feet

f = Moody friction factor

The resulting pressure drop for the 250 foot conveyance from the incinerator to the space heating boiler using 2 1/2 inch pipe was 12 psi which was felt to be unacceptable. Thus, the next higher uniform pipe size of 3 inches was tried and this resulted in a pressure drop of 5 psi.

The resulting pipe size from the incinerator to the space heating boiler of 3 inches is suggested. This same size pipe is assumed to continue through the building to the process boiler room where the steam is fed directly into the supply lines at about 143 psig. The condensate return line is assumed to be about one half the supply steam line or about 1-1/2 inches.

Steam was selected as the thermal conveyance medium, rather than high temperature water, to be compatible with the existing process steam needs. If the refuse fired incinerator heat should be used only to supplement the space heating demand, a water distribution system should be seriously considered rather than steam.

B.1.1.3 Site plan. A site plan is sketched out in Figure 5.6. The existing boiler rooms are positioned with inadequate space nearby to install a modular incinerator and space for at least one days refuse storage. The proposed incinerator location lies outside the fenced area across the parking lot from the present building complex. A 250 foot thermal conveyance line will be required to deliver steam to the building and to return the condensate.

A separate building will be required to house the modular incinerator and tipping floor. The tipping floor must be large enough to handle six tons of paper and wood refuse.

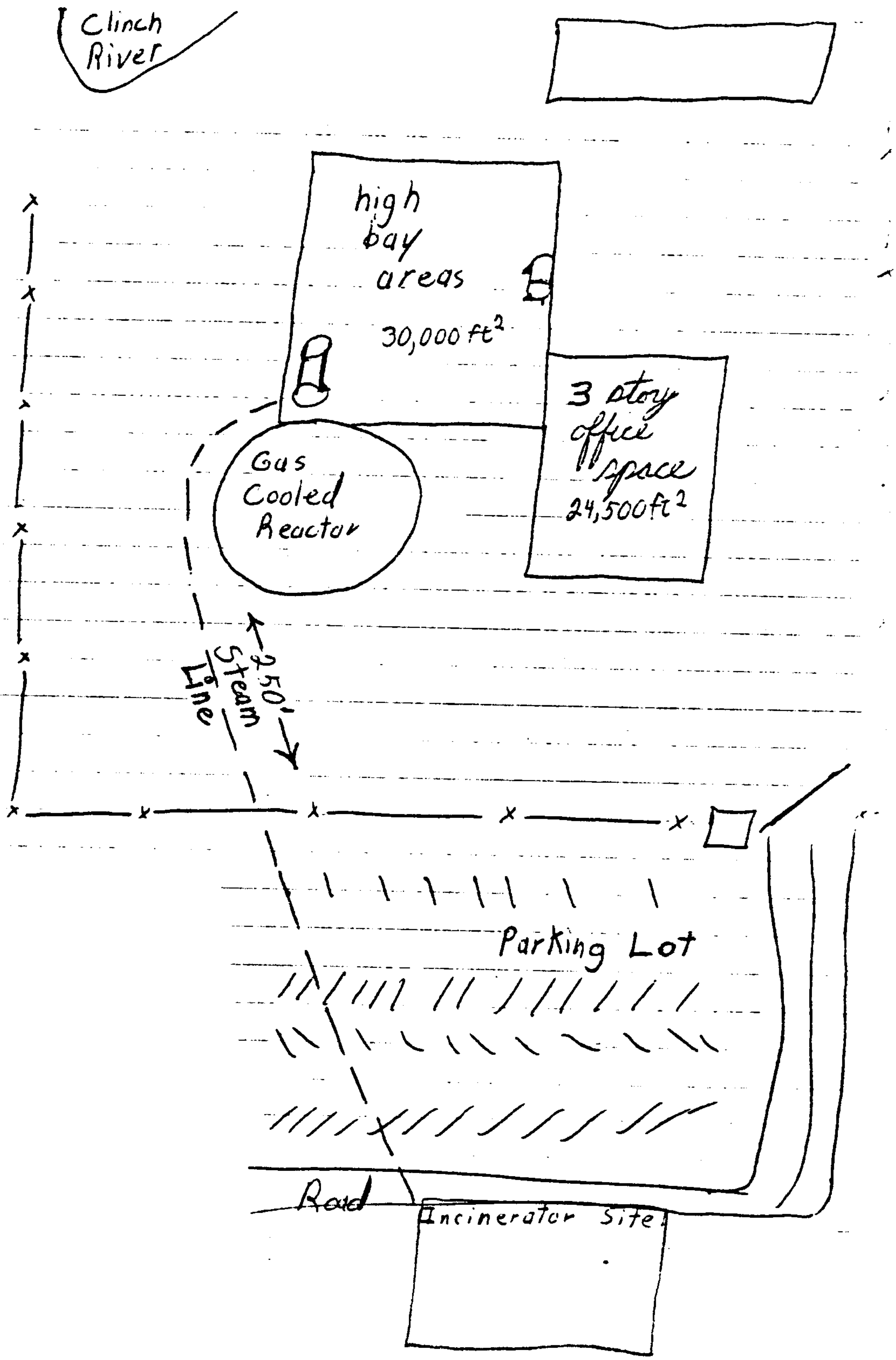


Figure 5.6. Building 7601 site plan.

A basic floor plan of a system to handle 6 tons per day of MSW, is shown in Figure 5.7. The area specified requires a total area of 60 feet by 40 feet, about 1,400 ft^2 of enclosed building area would be required to have adequate space for the tipping floor and incinerator feeding equipment. The height clearance required would be 19 feet. The space requirements for the incinerator/energy recovery equipment is approximately 25 feet by 40 feet. The tipping floor area adjacent to the equipment should be approximately 30 feet by 40 feet.

Various arrangements of the equipment may be developed depending upon the space available. Therefore, the requirements, as indicated above, are presented only as a guide.

B.1.2 Energy recovery

Table 5.14 shows the future energy load expected for the daily 8 hour shift between 7:00 a.m. and 5:00 p.m. The entire space heating load is assumed to be met during regular working hours, since the heating fan coils are shut off during unoccupied hours. One third of the total process heat is assumed to be needed during the same shift.

Table 5.14 also shows the high, low and average amount of waste heat available from the modular incinerator.

The solid waste heat estimate is based on about 1,667 tons of waste generated per year from ORNL. The high waste heat estimate is based on 7,000 BTU/pound with a modular incinerator efficiency of 60%. The medium heat estimate and most likely, is based on 6,000 BTU/pound and an incinerator efficiency of 55%. The low estimate is based on 5,000 BTU/pound with an incinerator efficiency of 50%.

Table 5.14 also shows a range of possible auxiliary fuel demands.

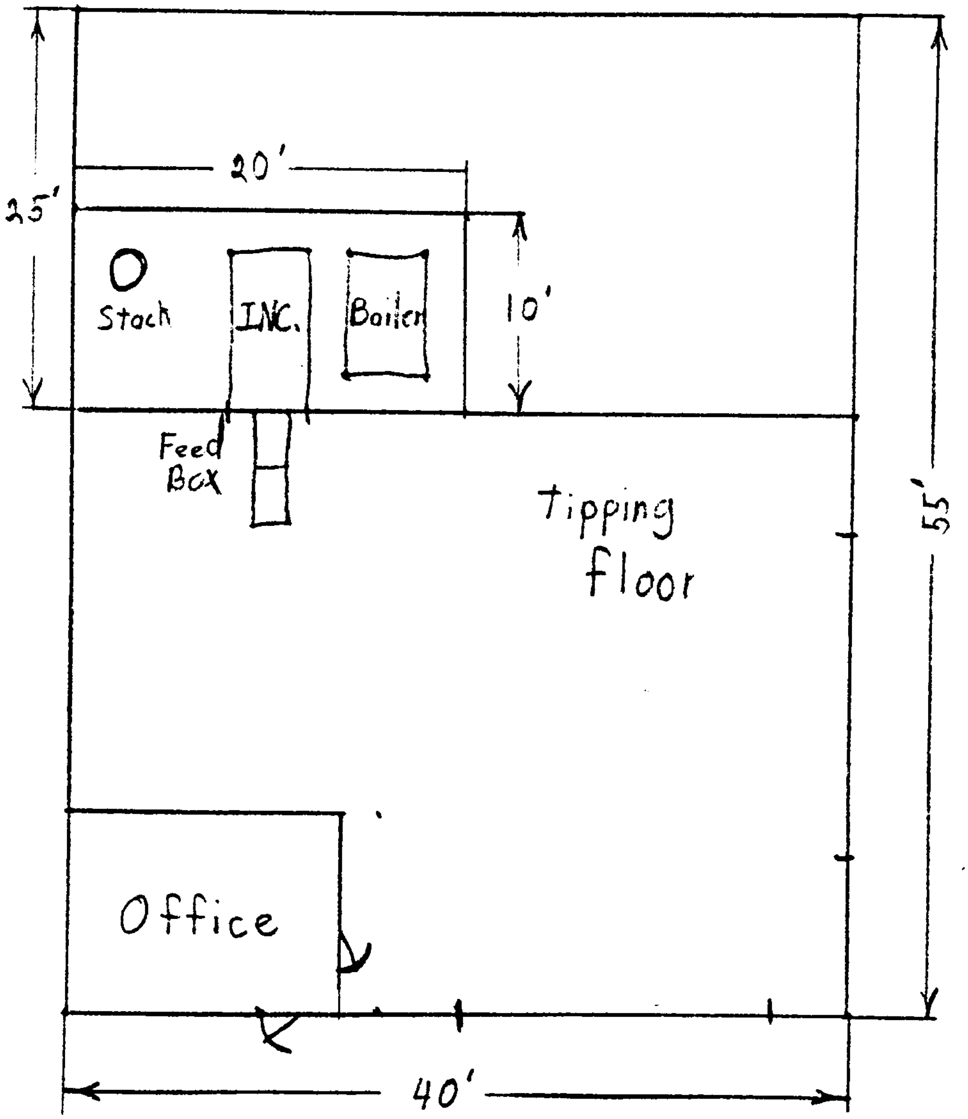


Figure 5.7. ORNL incinerator building floor plan.

Table 5.14. Future average daily energy demand from 7:00 a.m. - 5:00 p.m. in Building 7601 complex

Month	Heating Load	Solid Waste Heat Available (10^6 Btu)			Auxiliary Oil Consumed		
		High	Medium	Low	High	Medium	Low
June	1,082	1,008	792	600	120	66	43
July	1,082	1,075	845	640	128	70	46
August	1,082	1,058	831	630	126	69	45
September	1,082	1,394	1,095	830	166	91	59
October	1,380	1,537	1,208	915	183	101	65
November	1,550	1,142	897	680	136	75	49
December	1,728	1,067	838	635	127	70	45
January	1,694	1,285	1,010	765	181	84	55
February	1,558	1,168	918	695	139	77	50
March	1,487	1,260	990	750	150	83	54
April	1,353	1,050	825	625	125	69	45
May	1,082	958	753	570	114	63	41
Total	10,158	14,002	11,002	8,335	1,695	917	595

The high auxiliary oil consumption estimate assumes poor operation of the incinerator, numerous hours of under and overfiring resulting in an ICOP of 5.

The medium auxiliary oil consumption and most likely estimate, assumes an ICOP of 12, which is consistent with properly operated modular incinerators reported in Section V.A.2. The solid waste heat availability used for this estimate was based on 6,000 BTU/pound and an efficiency of 55%.

The low auxiliary oil consumption assumes an ICOP of 14, refuse energy content of 5,000 BTU/pound and 50% incinerator efficiency.

The available heat from burning all of ORNL's refuse during one shift per day, five days per week, will be needed to help meet the projected energy demands of the Building 7601 complex. Table 5.15 shows the percentage of energy demand that can be met by the refuse and auxiliary fuel energy. The medium auxiliary fuel estimate is added to the available refuse energy for all three cases to determine the percentage of energy demand met by refuse incineration.

B.1.3 Technical evaluation

B.1.3.1 Refuse characteristics. To date no refuse sampling and analysis has been conducted on ORNL's refuse, such as hand-sorting and weighing to determine the accuracy of the visually estimated composition.

On-site moisture analysis should be undertaken. The procedure is to determine sample gross and tare weights. To do this, dry the sample overnight at 105°C and reweigh the sample to determine the dry weight. The water percentage is computed by Equation (5.4).

Table 5.15. Percentage of daytime energy demand met by incineration

Month	High	Medium	Low
June	98	77	59
July	104	82	62
August	102	80	61
September	134	106	81
October	117	92	70
November	77	61	46
December	65	51	39
January	79	62	48
February	78	62	47
March	89	70	53
April	81	64	49
May	93	73	56
Average	93	73	56

$$H_2O\% = \frac{\text{gross wt}_{wet} - \text{gross wt}_{dry}}{\text{gross wt}_{dry} - \text{tare wt}} \qquad (5.4)$$

Another procedure which should be undertaken to determine more accurately refuse characteristics, is an ultimate analysis and heat content analysis.

The heat content is determined by using a bomb calorimeter. The device consists of an insulated vessel containing a known weight of water. A weighed amount of refuse and an excess of oxygen are introduced under pressure into a reaction chamber. The reaction mixture is ignited by means of an electrical resistance wire sealed into the reaction chamber. The heat produced by the reaction changes the temperature of the water, which is stirred to keep its temperature uniform. From this temperature change and from the amount of heat required to raise the temperature of the calorimeter and its contents by one degree, the heat of combustion per mole of refuse burned, can be calculated.

The ORNL refuse is estimated to have 72% paper and cardboard, 3% plastics, 10% organics, 8% wood and waste and 10% noncombustibles by weight. Table 5.16 shows the approximate ORNL refuse composition. The moisture content is estimated at 25%, which is consistent with Type I waste.

Based on the approximate refuse composition shown in Table 5.16 and published analysis from Purdue University,[44] an estimated ultimate analysis is derived as shown in Table 5.17. The Purdue University data contains an average ultimate analysis of each component found

Table 5.16. ORNL approximate refuse composition

Material	Percent of total (weight basis)
Paper (corrugated)	72
Glass	2
Metal	5
Plastics	3
Organics	10
Wood	8
Total	100

Table 5.17. ORNL refuse element ultimate analysis estimate

	Paper	Plastics	Organics	Glass	Wood	Metal	Total
Carbon	.312	.018	.043	.02	.040	--	.31
Hydrogen	.042	.002	.0059		.005	--	.041
Oxygen	.319	.007	.0412		.034	--	.301
Nitrogen	.002	0	.002		0	--	.003
Sulfur	.001	0	0		0	--	.001
Noncombustibles	.043	.003	.008	.02	.001	.05	.094
Water							.25
Total							1.00

in municipal refuse. A table titled "Composition and analyses of average municipal refuse" is found in the Appendix.

B.1.3.2 Residue characteristics. Tests run on a Kelly modular incinerator, burning in Marysville, Ohio, found the residue density to be 428 kg/m^3 (726 lb/yd). In the aproximate analysis 2.75% of the residue was found to be unburned combustibles. The refuse containing about 5.2% inerts, reduced by weight 94.6%.

B.1.3.3 Systems mass balance. The system mass balance, compares the mass flows entering and leaving the incinerator-heat recovery system. The system inputs are the refuse, the combustion fan air, the auxiliary fuel, the residue cooling water and the aspirator fan air. The system outputs are the residue and the boiler exhaust flue gas. Figure 5.8 summarizes the mass balance results on a per ton of refuse input basis.[45]

Up to this point in the analysis, the incinerator heat recovery and refuse heat content have been based on performance of modular incineration in other installations, and that ORNL has approximately Type 1 waste which contains around 6,500 BTU/pound. The ultimate analysis in Table 5.17, along with the energy balance, results from the Marysville incinerator, are used in the following material and heat balance calculation shown in the Appendix to predict the performance of a modular incinerator burning an average daily refuse load from ORNL.

Mass balance 120-hour test*

Source	Input: Mg per Mg refuse or Ton per ton refuse	Input: % of Total	Output: Mg per Mg refuse or Ton per ton refuse	Output: % of Total
Refuse	1.00	4.99		
Cooling spray water	0.65	3.24		
Natural gas	0.02	0.10		
Combustion air	18.39	91.67		
Flue gases			20.01	99.80
Residue, dry			.04	0.20
Total	20.06	100.00	20.05	100.00

* Total refuse input 25.6 Mg (28.3 tons).

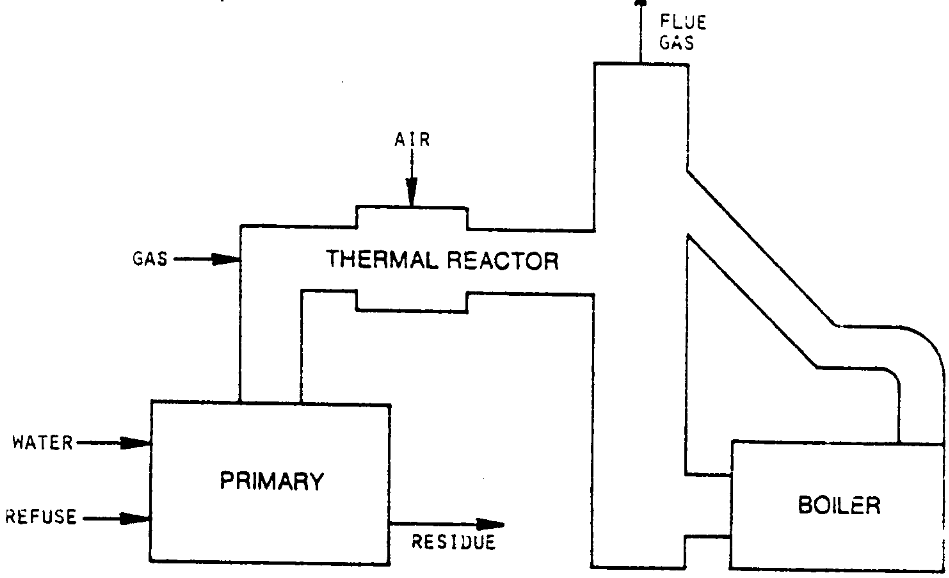


Figure 5.8. Mass balance for incineration-heat recovery processes in Marysville facility during the 120-hour (75.5-hour heat recovery) July field test.

B.1.3.4 Combustion efficiency.

B.1.3.4.1 Efficiency of refuse combustion. The combustion efficiency of the refuse on a dry basis is calculated by the heat loss method:

$$n = 1 - Qr/Qt$$

where:

Qr = sensible heat and unburned combustible's energy in the residue

Qt = total refuse energy

Substituting the values for Qr and Qt from the Heat Balance calculation shown in the Appendix, yields an efficiency of 99%.

B.1.3.4.2 Efficiency of the incinerator system. The efficiency of the incinerator system, is that percentage of the total energy in the refuse and combustion air which after its conversion to hot gases is available to the heat recovery system. Equation (5.5) uses the heat loss method to compute the incinerator system efficiency.

$$n = 1 - \frac{Qr + Qw + Qrc}{Qt} \qquad (5.5)$$

and the net efficiency is computed by:

$$\text{net } n = 1 - \frac{Qr + Qrc}{Qt - Qw} \qquad (5.6)$$

where:

Qr = sensible heat and energy remaining in the residue ($.35 \times 10^6 + .23 \times 10^6$)

Qw = latent heat of vaporization of refuse moisture and losses due to hydrogen combination ($3.47 \times 10^6 + 4.7 \times 10^6 + .42 \times 10^6$)

Qrc = heat lost by radiation and convection up to the boiler generation (4.33×10^6)

Qt = total input energy

The substitution of the values from the energy balance in the above equations, gives an incinerator efficiency of 84% and a net efficiency of 94%.

B.1.3.4.3 Effectiveness of boiler. The effectiveness of the boiler is the ratio of the actual heat transfer rate in the exchanger to the thermodynamically limited maximum possible heat transfer rate which could be realized only in a counterflow heat exchanger of infinite heat transfer area. This is expressed in Equation (5.7).

$$E = \frac{Th_1 - Th_2}{Th_1 - Tc_1} \tag{5.7}$$

where:

Th_1 = temperature of flue gas entering the boiler

Th_2 = temperature of flue gas exiting the boiler

Tc_1 = temperature of feed water entering the boiler

During an actual test at Marysville, the Th_1, Th_2, and Tc_1 temperatures averaged 1400°, 275°, 160°F, respectively. Consequently, the boiler effectiveness was 90%.

B.1.3.4.4 Thermal efficiency of boilers. While the effectiveness is the maximum theoretical performance of the boiler, the actual operational efficiency can be calculated by Equation (5.9).

$$n = \frac{\text{heat transferred to water}}{\text{sensible heat of gases into boiler}} \tag{5.8}$$

$$n = \frac{Mw\ (h_2 - h_1)}{MgCp\ T_1} \tag{5.9}$$

where:

Mw = mass of water entering

h_2 = enthalpy of water leaving

h_1 = enthalpy of water entering

Mg = mass of flue gas entering

C_p = specific heat of flue gas entering

T_1 = temperature of flue gas entering

The efficiency of the boiler with high heating value of the flue gas was reported at 80% and with the lower heating value of the flue gas, 84%.

B.1.3.5 <u>System efficiency</u>. The system energy efficiency is calculated by Equation (5.10)—using the heat loss method.

$$n = 1 - \frac{\Sigma\ \text{heat losses}}{\text{total heat input}} \tag{5.10}$$

The total heat inputs are: the auxiliary energy of 7.22×10^6 BTU (assumes an ICOP = 12), electricity of $.615 \times 10^6$ BTU (on test data at the Marysville-Kelly incinerator,)[32] and the refuse 86.6×10^6 BTU. The heat losses are the flue gases, 25.7×10^6 BTU (based on Marysville data[32]); radiation and convection losses, 4.33×10^6 BTU and residue 0.58×10^6 BTU. Substituting these values in the heat loss equation, yields a thermal efficiency of 67%.

B.1.4 Operating and maintenance consideration

A full time operator will be required to attend to the modular incinerator continuously during normal operating periods. A 10 hour burn schedule, 5 days per week, has been specified to overlap the period in which most of the energy for space heating and process steam is required at ORNL. Discussions with steam plant operators indicate that as people begin arriving at work between 7:30-8:00 a.m., the steam load begins to rise. The warm-up period reportedly takes less than a half hour. Therefore, if the burn cycle begins around 7:00 a.m., steam should begin flowing by 7:30. The operator will need at least one half hour to remove the ash from the previous days operation, unless automatic ash removal is purchased.

A small front-end loader will be used to carry the refuse from the tipping floor into the hydraulic ram charger. The small compactor, carrying about 4 tons per day, will arrive daily along with 4-5 "trash trucks" carrying about a half ton per trip. The large compactor which holds about 9 tons, and currently makes 2 trips per month to the landfill, can be used as buffer storage capacity. The truck could be scheduled to unload in time of cold weather during the month or heavy process steam loads.

The operator will have to refire the incinerator about every 8 minutes. A start button is pushed to begin the automatic loading cycle. An occasional jam may be corrected by the operator with a stop push-button. A second operator must be close at hand to relieve the primary operator as needed. After the last charge, the auxiliary fuel remains on for an additional three hours to insure that combustion in the primary and secondary chambers is complete. Air remains on until the unit shuts down for the next morning clean-out. The air assists in cooling and final combustion. For additional O & M details the reader is encouraged to read Section V.A.2.

B.1.5 Environmental evaluation

There are two air pollution standards that the modular incinerator must satisfy in Tennessee.

The first is particulate emissions which is specified as less than 4 lbs per ton of refuse burned. The second standard pertains to the flue opacity. If the modular incinerators are operated properly, i.e. no excessive overfiring, nor underfiring, both the above state pollution standards will be satisfied as shown in Section V.A.2.

The incinerator site should be far enough away from the large EGCR reactor so as not to cause any downwash effects. Some water emissions will result from the daily washing down of the tipping floor and boiler blow down. The runoff should be collected and treated with the rest of the runoff in the Building 7601 area.

Almost all of the modular incinerators can meet OSHA specifications, Section 1910 for:

Guards covering moving parts

Guards for pinch points

All access ladders

All catwalks

Within the incinerator building at Marysville, the fugitive dust levels were low, and no noise levels exceeded the OSHA limits.[32]

B.1.6 Cost analysis

B.1.6.1 Capital cost

B.1.6.1.1 Incinerator. A short letter describing the modular incinerator design reported in Section V.A.1.1 was sent to 16 manufacturers who were thought to sell small modular incinerators. A copy of the letter is provided in the Appendix. Three of the manufacturers are believed to produce minimum size units, exceeding the requirements at ORNL:

	Minimum Capacity (TPD)
Clear Air, Inc.	44
Giery Company, Inc.	22
Scientific Energy	150

Four companies, at the time of this writing, failed to respond to the letter of inquiry, which is taken to mean they do not have an available unit to satisfy the 6 TPD ORNL refuse loads.

Seven companies did respond with letters, technical descriptions, performance data, and a cost estimate.

Table 5.18 shows the estimated capital cost for the modular incinerator as provided by the manufacturers. The cost proposal details are available, however, in general, all of the major components are included; incinerators, ram feeder, controls, steam heat recovery boiler, stacks and interconnections between components. In all cases, a one year performance warranty is included. Some of the proposals mention the inclusion of delivery costs to Oak Ridge, emission guaranty, start-up supervision, installation labor, complete design drawings for the incinerator equipment and building operating manual and spare parts lists.

In general, the items not furnished by the manufacturers are shown in Figure 5.9. The total capital cost (1980 dollars) estimates shown in Table 5.19 account for the unfurnished items. Table 5.19 shows a high, most likely and low capital cost estimate.

The high capital cost estimate uses the second highest incinerator installed budget price of $300,000 and the low estimate uses the lowest received capital cost figure provided by the responding manufacturers. The front-end loader cost varies from $50,000 to $16,000. The recommended machine for transferring the refuse from the tipping floor to the feeder box is a small 35 hp tractor. Figure 5.10 shows a picture of one of these units. A cost estimate from a local vendor indicated a capital cost for one unit, of $16,000. With the front-end loader directly charging the incinerator, the operator needs to charge the

Table 5.18. Manufacturer's provided budget prices (January 1980 dollars)

Manufacturer	Equipment	Installation	Total
A	350,000[a]		
B	--	--	203,310
C	238,785[a]	50,000	288,785
D	186,313		
E	153,000	26,000	179,000
F	150,000	40,000	190,000
G	--	--	300,000[a]

[a]Automatic ash removal.

Concrete platforms

Fuel oil lines

Building

Steam pipes

Steam fittings

Pressure reducing valve

Steam valve

Make-up water meter

Water make-up feeder

Steam connections

Electrical wiring (480/3/60)

Plumbing sewage

Boiler feed water (domestic water)

Architectural plot plan of proposed building site

Soil analysis to determine load bearing capabilities

All applicable permits:
- State
- Local building
- Sewer
- Water
- Unit operational permits

Water tie-in for the FM sprinkler system

Condensate tank steam heater

Figure 5.9. Items not furnished by modular incinerator manufacturer.

Table 5.19 Total capital costs (1980 dollars)

Item	High	Most Likely	Low
Incinerator	300,000	250,000	190,000
Front end loader	50,000	20,000	16,000
Building, 1400 ft^2	46,550[a]	26,600	21,000
Steamlines	15,000	7,500	7,000
Design	15,000	12,500	8,000
	426,550	316,600	242,000
Contingency 15%	63,983	47,490	36,300
	490,532	364,090	278,300

[a] 2450 ft^2 building.

Figure 5.10. Front end refuse loader.

incinerator every 8-10 minutes. There are automatic chargers available shown in Figure 5.11, which can hold about 3 to 4 charges. The feeder hopper would require the front-end loader to tend the system once every half hour. The remaining dollars above the $16,000 allocated for the front-end loader could be used to add an element of automation to the incinerator feeding procedure.

B.1.6.1.2 Building. The building capital costs vary from $46,550 to $21,000. The most likely building cost is estimated to be $26,600.

The building described in Section V.B.1.1 calls for approximately 1400 ft^2. The cost of the Butler Building in Crossville, Tennessee in 1976 was $\$11.30/ft^2$. Today, this cost would be about $\$15/ft^2$. This cost includes sewer hookups, potable water, electric distribution lines and a very small office. The building consists of a steel prefabricated structure raised approximately six feet from ground level, with the interior floor a concrete flat slab. The slab should be sloped to floor drains to permit high pressure hosing.

The total steam line capital costs are estimated to vary from $15,000 to $7,000. The steam pipe costs were from reference 47 and consist of schedule 40 steel with prefabricated lengths with 10 ga metal casings, asphalt coated on fiberglass screen and spiral wrapped with asbestos felt. The $/ft of prefabricated conduit quoted, includes a typical allowance for freight and for services of a field engineer to perform critical period supervision.

The most likely costs also include, a recommended 35% for expansion loop allowance, and another 50% of the quoted costs was added to give the installed cost. The installed cost for a 3 inch diameter pipe is $23/ft (1977 dollars).

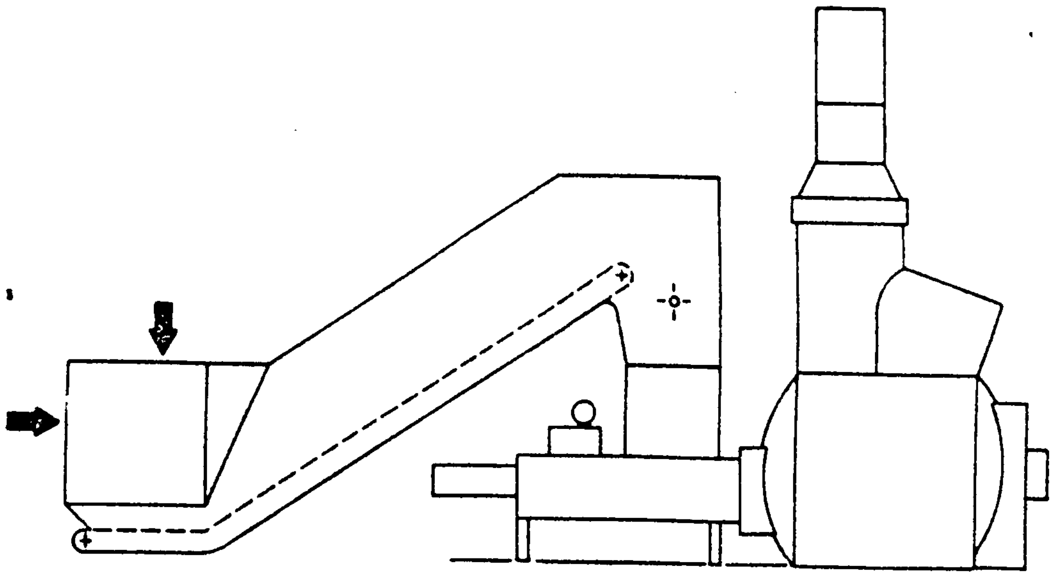


Figure 5.11. Automatic refuse charger.

B.1.6.1.3 Design. The most likely design cost estimate is $12,500 which was the reported design cost for the same size incinerator installed in Marysville, Ohio. The T & M Engineering contractor, cost at ORNL is $25/hour. The most likely design estimate would provide almost three man months of effort.

B.1.6.1.4 Total. After adding in 15% for contingency, the capital cost estimate varies from a high of about $500,000 to a low of about $300,000. The expected life of this equipment is 15 years and manufacturers report delivery time from 15 to 30 weeks.

B.1.6.2 Operating and maintenance cost. The dominant operating and maintenance cost associated with running a modular incinerator is labor, as shown in Table 5.20. The Marysville, Ohio, Kelly incinerator is operated by one person. However, a number of manufacturers suggest that more than one person will be needed occasionally to sustain steady operation of the incinerator.

Union requirements at ORNL may require a boiler operator and a heavy equipment operator. The cost for a heavy equipment operator is $36,600, including fringe benefits and overhead and $25,000 to $30,000 for a boiler operator. The cost of salaries shown in Table 5.20 vary from a high of $81,000 to $32,400. The most likely estimate assumes the heavy equipment operator and the boiler operator will require $66,528 per year. The electricity, water, sewer and chemical costs are all based on the actual expenses from the Kelly incinerator in Marysville. The most likely maintenance cost of $10,643 is 3.5% of depreciable capital assets. The 3.5% value is used rather than 5.5%,

Table 5.20. Annual operating and maintenance cost for a modular incinerator at ORNL (January 1980 dollars)

Cost	High	Most Likely	Low
12-Month Operation			
Salaries	81,000	66,528	32,400
Electricity	1,330	1,330	1,330
Water and sewer	270	270	270
Maintenance	18,797	10,643	10,500
Chemical	130	130	130
	101,527	78,901	44,630

which is an IRS guideline for solid waste processing plants, because the operators will have sufficient time to do some of the maintenance work. The total operating and maintenance cost for a full twelve months operation is estimated to vary from \$101,527 to \$44,630 per year.

B.1.6.3 Savings. Three types of cost savings, shown in Table 5.21, will occur by incineration with heat recovery; energy displacement, hauling and landfilling.

B.1.6.3.1 Energy. The energy cost savings varies from \$125,354 to \$49,063. The high estimate assumes all the recovered energy can be used by the Building 7601 complex. The high energy displacement scenario is assumed as described in Section V.B.1.2. The calculated energy available is $13{,}085 \times 10^6$ BTU. The cost savings must reflect the energy type displaced. Presently, oil is used at a current cost of around $\$6/10^6$ BTU. If electrode boilers are installed to meet future energy needs in the Building 7601 complex, the present cost converts to about $\$8.50/10^6$ BTU or \$0.029 per kwhr.

The real escalation rate for oil suggested in the April 30, 1979, Federal Register for Department of Energy Facilities in Region IV is about 4% and about 1.5% for electricity. With an incinerator lifetime of 15 years, the average cost for oil will be $\$8.21/10^6$ BTU, and $\$9.58/10^6$ BTU for electricity.

If oil displacement is assumed, the high energy savings converts to an average of \$107,428 per year. If electricity displacement is assumed, the energy savings converts to an average of \$125,354.

Table 5.21. Annual savings by a modular incinerator at the Building 7601 complex (January 1980 dollars)

Cost	High	Most Likely	Low
12-Month Operation			
Energy	125,354	86,953	49,063
Hauling	17,036	15,333	15,333
Landfill	39,600	35,640	35,640
Total	181,990	137,926	100,036

The most likely savings estimate assumes that 90% of the refuse energy can be used. The medium energy displacement scenario is assumed as described in Section V.B.1.2. The calculated energy available is $9{,}077 \times 10^6$ BTU. The oil displacement cost savings would be \$74,518, and electric displacement cost savings would be \$86,953.

The low savings estimate assumes that 90% of the refuse energy can be used. The low energy displacement scenario is as used as described in Section V.B.1.2 with an ICOP of 5.

B.1.6.3.2 Hauling. The estimated hauling cost in 1980 dollars, by 1988 is estimated in Section IV.B to be \$14.75/ton. The high cost estimate savings assumes that only 70% of the hauling cost can be saved by siting the incinerator at the Building 7601 complex. The proposed incinerator site is 2 miles from the east end of the ORNL main facility and the landfill is 8.5 miles. The most likely and low estimate in Table 5.21 assumes an incinerator reliability of .9, which reduces the hauling cost savings.

B.1.6.3.3 Landfilling. The estimated landfilling cost, in 1980 dollars, by 1988, is estimated in Section IV.B. to be \$24.00/ton. The landfill cost savings estimate varies from \$39,600 to \$35,640.

B.1.6.3.4 Total. The total annual savings estimate from modular incineration with heat recovery at the Building 7601 area, varies from \$182,000 to \$100,000.

Table 5.22 shows the average net annual cash flow not counting the investment capital nor cost of borrowing the capital. The value

Table 5.22 Annual savings minus operating and maintenance cost (1980 dollars)

Savings	O & M High	O & M Most Likely	O & M Low
High	80,463	103,089	137,360
Most likely	36,399	59,525	93,296
Low	-1,491	21,635	55,406

shown in Table 5.22 represents annual savings from Table 5.21, minus the annual operating and maintenance cost from Table 5.20. The cash flow varies from a high of $137,360 per year to a -$1,491. The most likely estimate is $59,525 per year.

The discounted payback, using 10% as specified by the DOE Rules in the April 30, 1978, Federal Register, depends on the initial capital cost estimate. Tables 5.23 through 5.25 show the range of discounted paybacks, under the various cost scenarios. For the low capital cost estimate of $278,300, the most likely payback is 6.6 years. Table 5.24 shows that with the most likely capital cost estimate of $364,090, the discounted payback is 10 years.

The calculated payback estimates shown in Tables 5.23-5.25, assume the incinerator is operated only one shift per working day. If the process steam load at Building 7601 is going to be a 24 hour per day load for long periods of time, conceivably additional refuse could be hauled in from Y-12 and K-25. Currently, ORNL only contributes 22% of the entire landfilled refuse at the Y-12 landfill site.

Table 5.26 shows the net cash flow not counting capital costs for the modular incinerator burning for two shifts per working day. The facility assumes the refuse hauling expense of $14.75/ton and the operating and maintenance costs are doubled.

Table 5.27 shows the discounted payback for the incinerator facility, buring 12-14 tons per day in two shifts, for the high initial captial cost. The most likely payback is 8.2 years, using the high capital cost estimate of $500,000.

Table 5.23. Discounted payback period based on the low initial capital investment (years)

Savings	O & M High	Most Likely	Low
High	4.5	3.5	2.2
Most likely	15	6.6	3.8
Low	--*	--*	7.3

*No payback in less than the life of the incinerator of 15 years.

Table 5.24. Discounted payback period based on the most likely initial capital investment (years)

Savings	O & M High	O & M Most Likely	O & M Low
High	0.5	4.5	3.5
Most likely	--*	10	5.2
Low	--*	--*	11

*No payback in less than 15 years.

Table 5.25. Discounted payback period based on the high capital investment of $490,523 (years)

Savings	O & M High	O & M Most Likely	O & M Low
High	6.1	6.8	4.5
Most likely	--*	--*	7.4
Low	--*	--*	--*

*No payback in less than 15 years.

Table 5.26. Annual savings minus operating and maintenance cost of burning 12-14 tons per day in two shifts (1980 dollars)

Saving	O & M High	O & M Medium	O & M Low
High	120,000	170,000	240,000
Medium	40,000	90,000	150,000
Low	-35,000	10,000	78,000

Table 5.27. Discounted payback based on the high initial capital investment estimate, burning 12-14 tons per day in two shifts (years)

Saving	O & M High	Most Likely	Low
High	4.5	3.8	2.2
Most likely	--*	8.2	4.2
Low	--*	--*	10.5

*No payback in less than 15 years.

Table 5.28 shows the discounted payback for the incinerator facility, burning on two shifts for the capital cost estimate of \$364,090. The most likely payback, is reduced from 10 years burning on one shift to 5.5.

An additional \$30,000 savings could occur by discontinuing the computer paper and card recycling program and burning the 85-100 tons per year. This savings could be assumed if ORNL were to discontinue recycling the computer paper and cards and dispose of the material by the existing refuse collection system. This material could be incinerated and produce additional heat.

B.2 Modular incinerator with heat recovery located adjacent to the ORNL steam plant

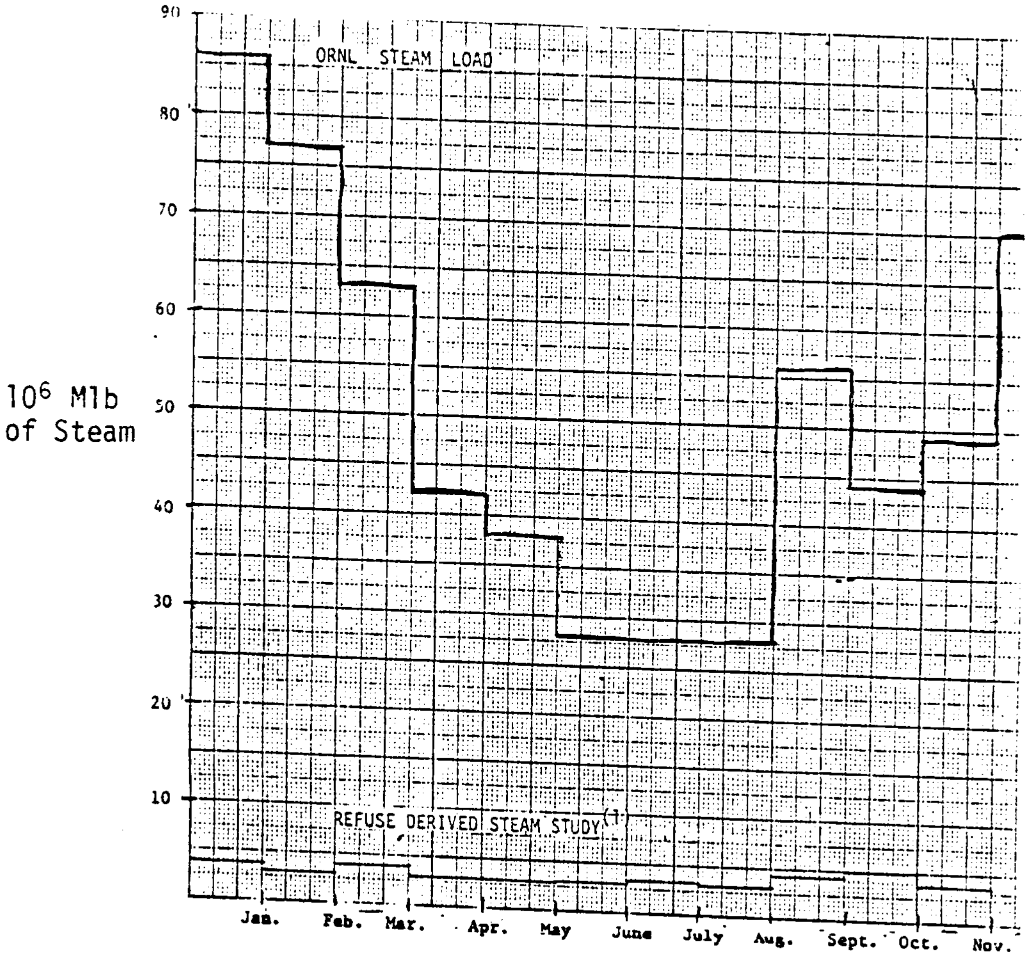
B.2.1 Design and description

The ORNL coal fired steam plant is located in the southwest corner of the main ORNL facility. The coal plant produces steam for distribution at 250 psig and 150 psig. The steam load fluctuates between 28,000 M lb/month and 86,000 M lb/month. Table 5.14 (page 80) showed that the highest available monthly refuse energy level is about 1600 M lb/month. Essentially all of the combustible refuse derived steam could be used by the ORNL main facility. The refuse energy could contribute about 2% of the total ORNL steam load. Even if the waste from the other Oak Ridge Energy facilities were to feed the ORNL modular incinerator plant, only about 7% of the total annual load could be satisfied. Figure 5.12 shows the 1978 ORNL monthly steam load and the potential fraction supplied by refuse generated by all three Union Carbide operated Oak Ridge facilities.

Table 5.28. Discounted payback based on the most likely capital cost estimate burning 12-14 tons per day in two shifts (years)

Saving	O & M High	O & M Most Likely	O & M Low
High	3.7	2.5	2
Most likely	--*	5.5	2.7
Low	--*	--*	7

*No payback in less than 15 years.



[1]Refuse from all three Union Carbide — Oak Ridge Facilities.

Figure 5.12. ORNL steam loads and potential refuse derived steam.

The proposed site is located outside the fenced area to the south. The location once supported an incinerator without heat recovery. The incinerator became too costly to maintain, and in 1960 was taken out of operation. The building designed to house the incinerator heat recovery equipment and the tipping floor are identical to the building described in Section V.B.1.1.

B.2.2 Energy recovery

The steam demand, even in the summer months, far exceeds the available energy supply from ORNL's refuse. The steam use if for process heating and space heating needs throughout the main complex. The existing steam plant has operated the 1979-1980 winter season with coal-fired boilers. A total of $\$14 \times 10^6$ has been expended to convert the existing gas fired boilers to coal. The use of a modular incinerator with heat recovery to displace coal, will result in an increase in oil or natural gas consumption, because of the need for auxiliary fuel.

B.2.3 Technical evaluation

The discussion on the technical evaluation found in Section V.B.1.3 applies to the same design as proposed for the modular incinerator sited at the Building 7501 complex.

B.2.4 Operating and maintenance considerations

The modular incinerator plant, located adjacent to the ORNL steam plant, will be operated in a similar manner as the earlier described incinerator facility in Section V.B.1.4. There will be one possible exception.

Because of the proximity to the already continuously monitored steam plant, possibly pertinent controls could be wired into the steam plant control room and watched by the steam plant operator on duty. The maintenance personnel could also be shared, much more readily than the more remote facility described in Section V.B.1.1.

B.2.5 Environmental evaluation

The environmental commentary, in Section V.A.2 and V.B.1.5, pertain equally well to the proposed facility adjacent to the ORNL steam plant. The specific site selected is away from the main traffic routes around the facility, so minimal traffic congestion should occur by siting as proposed.

B.2.6 Cost analysis

B.2.6.1 Capital cost. The capital costs are shown in Table 5.19 (page 91) and discussed in Section V.B.1.6.

B.2.6.2 Operating and maintenance cost. The operating and maintenance costs are shown in Table 5.29. The O & M cost estimates for the same size modular incinerator plant described in Section V.B.1.6, are used for display purposes for the ORNL steam plant, sited unit. An additional operating expense, if the refuse energy displaces coal, is the cost of auxiliary fuel. The auxiliary fuel consumption discussed in Section V.B.1.2 is used along with an assumed $8.21/$10^6$ BTU.

B.2.6.3 Savings. The savings potential for siting parallel with a coal fired steam plant, differ from the savings discussed in Section V.B.1.6. The energy cost savings shown in Table 5.30 are considerably less, varying from 31,500 to 18,754.

Table 5.29 Annual operating and maintenance cost of running a modular incinerator at ORNL (January 1980 dollars)

Cost	High	Most Likely	Low
Salaries	81,000	66,528	32,400
Electricity	1,330	1,330	1,330
Auxiliary fuel $8.21/$10^6$ BTU	7,529	6,776	6,776
Water and sewer	270	270	270
Maintenance	18,797	10,643	10,500
Chemical	130	130	130
	109,056	85,677	51,406

Table 5.30 Annual savings by a modular incinerator near the ORNL steam plant (January 1980 dollars)

Cost	High	Most Likely	Low
Energy	31,500	24,755	18,754
Hauling	24,338	21,904	21,904
Landfill	39,600	35,640	35,640
Total	95,438	82,299	76,298

B.2.6.3.1 Energy. The high estimate assumes all the recovered energy can be used by the ORNL steam plant. The high energy displacement scenario in Section V.B.1.2 is assumed. The calculated energy displacement is 14,002 × 10^6 BTU. However, in order to obtain this energy, about 917 × 10^6 BTU of oil or gas must be consumed. The DOE rules in the April 30, 1979, Federal Register, suggest that in 1985 coal will cost \$2.25 × 10^6 BTU. Presently, ORNL is paying about \$2.00 per 10^6 BTU for coal. The high coal energy savings converts to \$31,500.

The most likely savings estimate assumes that 90% of the refuse energy displacement scenario described in Section V.B.1.2, is assumed. The estimated energy displacement converts to 11,002 × 10^6 BTU or \$24,755 per year. The low energy displacement is 8,335 × 10^6 BTU or \$18,754.

B.2.5.3.2 Hauling. The estimated hauling cost, in 1980 dollars by 1988, is estimated at \$14.75/ton. The full cost is assumed to be saved, if an incinerator is sited at the main ORNL facility. The most likely and low estimate assume 90% of the refuse is successfully burned in the incinerator.

B.2.6.3.3 Landfilling. The same landfilling cost savings is assumed for this design as described in Section V.B.1.6, \$39,600 to \$35,640.

B.2.6.3.4 Total. The total annual savings estimated for modular incineration with heat recovery at the ORNL steam plant site, varies from 95,438 to 76,298.

Table 5.31 shows that only if the low O & M cost and the high savings estimates occur, will the modular incinerator facility be able to payback when displacing coal, at the ORNL steam plant. The annual net cash flows shown in Table 5.31 do not include the investment capital nor the cost of borrowing the capital.

B.3 Refuse derived fuel burned with coal in the ORNL steam plant

This option is not off the shelf technology. Further research and development is needed to seriously propose RDF for the ORNL steam plant, using the 1,650 ton per day waste load. RDF requires a large amount of equipment with continuously moving parts. Repairs are required frequently. Thus, redundancy in mechanical components should be included in the design. To afford the redundancy capabilities a larger refuse feed rate is required. At least two qualified technicians would be required to operate a small RDF facility at a cost of about $73,000 per year. Table 5.30 shows the most likely annual savings of $82,299 while burning refuse in the ORNL steam plant. This leaves about $9,000 per year to pay for the RDF facility, requiring shredders, air classifiers, automatic conveyors, storage and handling equipment plus the boiler retrofit costs. This option should not be foreclosed on other biomass or refuse streams. Possibly a mixture of local forest waste and refuse with the capacity of producing at least 50 tons per day would be feasible in the future. However, the best conversion process for ORNL waste-to-energy alone, is not RDF.

Table 5.31. Annual savings minus operating and maintenance cost for a modular incinerator near the ORNL steam plant (1980 dollars)

Saving	O & M High	O & M Most Likely	O & M Low
High	-13,488	9761	44,032
Most likely	-26,627	-3378	30,893
Low	-32,028	-9379	24,892

VI. DECISION ANALYSIS

A. Conceptual Approach

There are five major steps involved in determining the feasibility of utilizing institutional waste for useful energy: (1) define the present situation, (refuse disposal and energy costs); (2) examine the future anticipated refuse and energy costs; (3) select alternatives (recycling, modular incineration, RDF, district heating); (4) collect decision input data (technical, financial and environmental); (5) decide whether to act.

The first four tasks leading to the decision to act has been described in detail in earlier sections of this report. The decision to act is described in this section.

There are certain risks in any investment and if a procedure were capable of quantifying all risks, decisions could be made simply on the basis of single point estimates. The following text attempts to identify the risks involved in owning and operating a waste-to-energy facility, subjectively assign costs to potential incidents and probabilities of occurrence, and incorporate the risk uncertainty into the decision process.

A refuse-to-energy facility is an investment decision involving the commitment of funds now with the hope of returns in the future. Since the future is not known with certainty, the consequences of the decision are also uncertain. The uncertainty about the exact course of future events creates risks in the form of unforseen fluctuation in cash flow patterns and payback period.

The conventional approach to evaluation of investments consider two fundamental dimensions the magnitude and time. The traditional analysis is based upon expressing the assumptions about key variables in terms of single-point estimates. These estimates are based upon the best information available. Performance, cost, energy demand, refuse supply uncertainties (risk) can be explicitly and quantitatively considered.

Major input assumptions are described by not only a single estimate, but a variety of estimates with associated likelihoods of occurrence.

The uncertainties can be handled by assigning probabilities to the major cost components used to estimate the financial feasibility of owning and operating a refuse to energy facility. Table 6.1 shows the major cost components with the risks that affect the assigned values.

Each risk is thought of in regards to how it might affect the cost component it falls under. Probabilities are assigned based on the predicted likelihood that because of this uncertainty a high, most likely, or low cost will result.

The average of the risk probabilities determine the high, most likely and low cost component probabilities. Within each risk category a weighting scheme could be employed if certain risks were felt to be more dominant than others.

A decision tree can be used to graphically display the set of possible events. Figure 6.1 shows a decision tree for an institution studying four options available to incorporate institutional waste-to-energy. A decision tree is like a road map. It is a map of your decision problem and it includes only the events and your actions that are relevant to the problem. There are two types of forks; act forks,

Table 6.1. Risks affecting major cost components

	High	Most Likely	Low
Capital Investment			
Future environmental standards			
Cost of capital			
Refuse content			
Reliability			
O & M			
Boiler tube corrosion			
Inside tube fouling			
Explosion potential			
Reliability			
Union restrictions			
Energy Savings			
Energy escalation rates			
Energy needs			
Operating rate/design feed rate			
Refuse content			
Landfill and hauling savings			
Landfill costs			
Hauling costs			

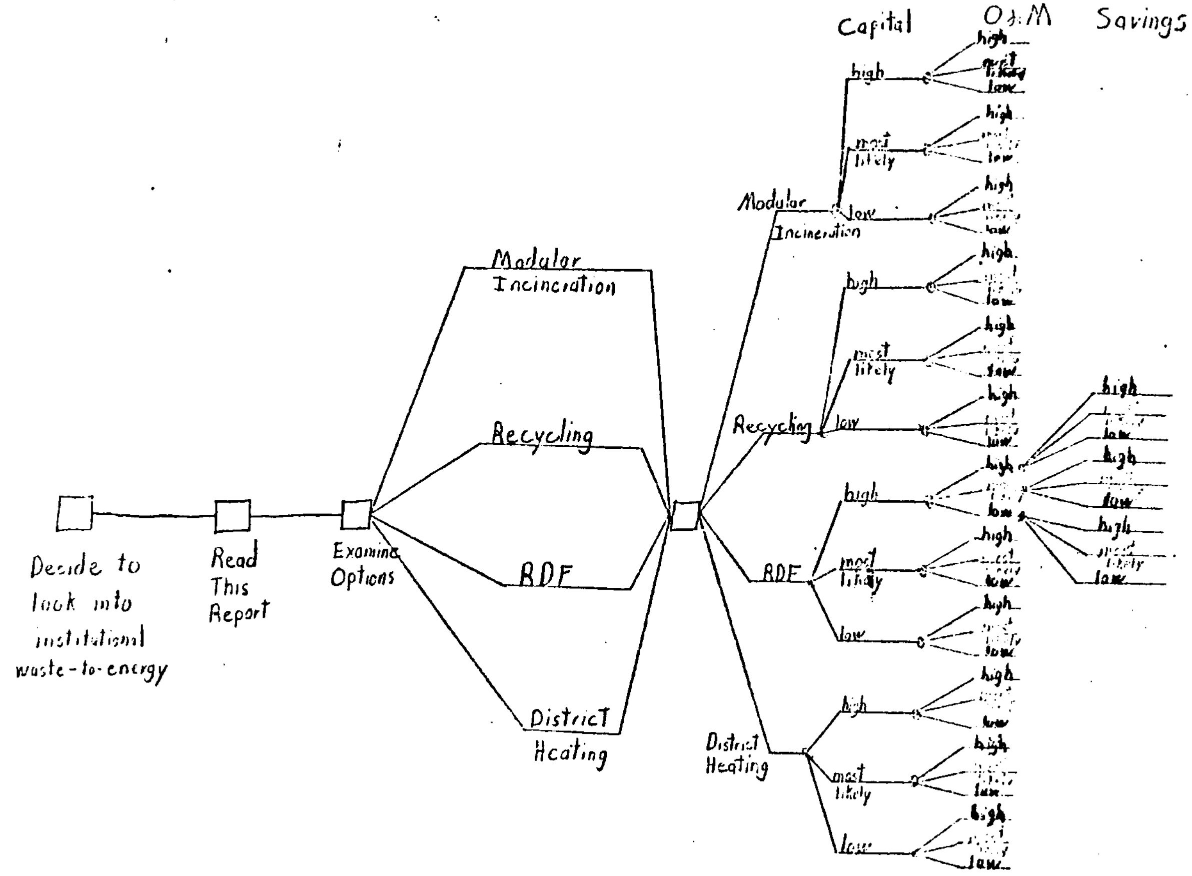


Figure 6.1. Decision tree for institutions contemplating waste-to-energy.

each branch represents one of the possible courses of action available to you; event fork, each branch represents all relevant consequences. The tree can be folded back once the resulting decision variables and probabilities for each option are determined. Each of the end positions is labeled with the levelized annual life cycle cash flow that each end branch represents. The goal of folding the tree back is to determine the probability-weighed value for each refuse-to-energy investment alternative.

The probability weighed value is a single number that represents the attractiveness of a large number of possible values which could result from the initial investment in refuse-to-energy. Each of the payback periods is weighed precisely by its probability of occurrence. Thus, like an ordinary mean, an "expected value" is a single measure intended to represent a set of scores. The expected value of each branch:

$$\text{result} \times \text{probabilities}$$

offers a decision variable to aid in trading off options. It must be pointed out that this is not necessarily an actually attainable expected value. Rather the expected value of a large number of institutions with similar alternative options available to them. However the expected value can be used as a ranking parameter that includes the benefit and an element of uncertainty or risk.

The tool is best employed as an interactive tool. The analyst should sit down with the decision maker(s) involved and assign probabilities to all major unknown events. Use the probabilities to assign weights to the high, most likely and low component cost scenarios and fold back the decision tree.

The same data inputs can be used in a variety of illustrative ways. The decision tree is only one. For instance a graph can be developed which shows payback periods versus the probabilities of paying back under a range of years.

B. Case Study Waste-to-Energy for ORNL

B.1. Decision statement

The problem is what, if anything, should I recommend to DOE pertaining to the investment in a refuse energy facility for the Oak Ridge National Laboratory. The generic alternatives I have considered are:

1. Modular incineration at the Building 7601 complex
2. Modular incineration near the ORNL steam plant
3. RDF co-fired with coal in the ORNL steam plant
4. Do nothing.

Without further analysis the third alternative may be eliminated for the following reasons:

1. The investment in refuse processing equipment will not pay for itself.
2. Burning RDF in the ORNL steam plant presents unacceptable risks of boiler tube corrosion, given the small 2% total coal displacement which will occur.

3. The ORNL steam plant recently underwent a $\$14 \times 10^6$ retrofit to burn coal. Problems are still being worked out on the retrofit equipment. Proposing an additional complication to this facility could jeopardize near term system reliability.

B.2 Intuitive preference

The fact that siting the modular incinerator plant near Building 7601 will displace oil offers a fuel savings benefit of 3 to 4 times the dollar savings resulting from coal displacement. The future energy demand growth at the Building 7601 complex will be increasing by a factor of 8. The hourly base load will be slightly more than the design energy recovery rate from a modular incinerator burning for one shift, five days per week.

All of the ORNL refuse can be handled in one shift. If a 24 hour base steam load will be needed, additional refuse can be obtained from the two other Oak Ridge facilities currently landfilling 7 miles away from the proposed incinerator site. The ORNL waste contributes only 22% of the total refuse disposed in the central landfill. This additional refuse can be purchased for the approximate hauling cost of \$8.40/ton and still produce a positive cash flow when all the recovered energy is needed.

The conservative payback period for installing a modular incinerator plant near Building 7601 appears to be less than 10 years. Plus the fact that the proposal will displace a large amount of potential oil consumption may give this project added incentive beyond energy conservation opportunities (ECOs) that displace electricity and coal energy. My intuitive preference is to propose to request funding for a modular incinerator with heat recovery located near Building 7601.

B.3 Identification of criteria (in order of importance)

1. Payback period. DOE generally will not fund an energy conservation opportunity with more than a 10-year payback. Union Carbide generally will not submit a proposal for funding to DOE unless the project has less than a 5-year payback.

2. Environmentally acceptable.

3. Compatibility with existing refuse collection and energy supply system.

B.4 Identification of uncertainty

The major areas of uncertainty are listed along with the major cost component they affect in Table 6.2.

Probabilities are first assigned to each of the risks. Each risk must be examined in relation to the assumptions that have gone into the derivation of the cost component estimate. For instance, the first risk listed under capital investment is future environmental standards. The most likely cost estimate assumes no increase in emission standards from those presently enforced. The addition of pollution control equipment will increase the capital cost. The probability assigned to the likelihood of this incident is 15%.

Each risk category is assumed to have equal weight in affecting the cost component in question. The probability of a high, most likely,

Table 6.2. Risks affecting the cost components for the modular incinerator at the Building 7601 complex

	High	Most Likely	Low
Capital Investment	.2	.75	.05
Future environmental standards	.15	.85	
Cost of capital	.15	.75	.1
Refuse content	.25	.7	.05
Reliability	.25	.7	.05
O & M	.05	.8	.15
Boiler tube corrosion	.1	.85	.05
Inside tube fouling	.05	.75	.2
Explosion potential	.05	.9	.05
Reliability	.05	.8	.15
Union restrictions	.0	.7	.30
Energy Savings	.1	.8	.1
Energy escalation rates	.15	.8	.05
Energy needs	.15	.75	.1
Operating rate/design feed rate	.05	.85	.1
Refuse content	.05	.8	.15
Landfill and hauling savings	.1	.8	.1
Landfill costs	.05	.8	.15
Hauling costs	.15	.8	.05

and low outcome of each cost component is determined by averaging the risk probabilities as shown in Equation (6.1).

$$y_{j,k} = \frac{\sum_{j=1}^{3} \sum_{i=1}^{N} x_{ij}}{N} \tag{6.1}$$

where:

x_{ij} = probability of risk occurrence

i = risk identifier

j = high, most likely, low risk probability

N = number of risks

y_{ik} = high, most likely, low cost probability

K = cost component identifier

Figure 6.2 shows a decision tree with the annual life cycle cost savings of implementing modular incineration at Building 7601. Two choices are shown, go with a modular incinerator or continue landfilling. The weighted annual savings is not a true measure of what would result, it should only be used as an indicator of the soundness of the investment.

Another way of displaying the decision uncertainty is by a cumulative probability as a function of payback period. Figure 6.3 shows that the base case of burning only ORNL's refuse for one shift per day five days per week has a 74% probability of paying back in less than 10 years.

Figure 6.4 shows another branch of the decision tree which involves arranging with K-25 or Y-12 to haul about 1500 tons/year of their combustible refuse to the Building 7601 complex for combustion. The

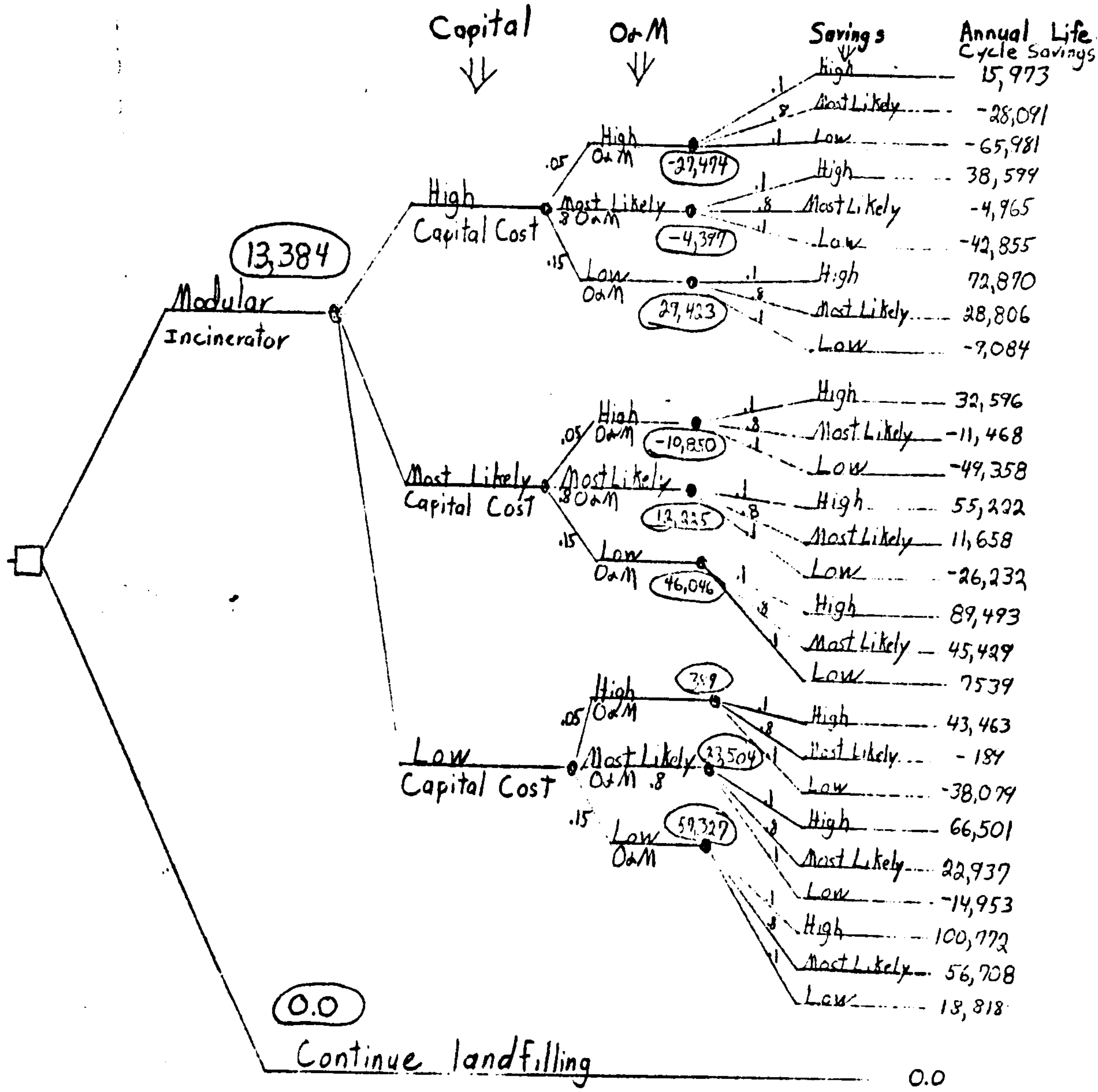


Figure 6.2. ORNL decision to select the modular incinerator operating one shift per day or continue landfilling.

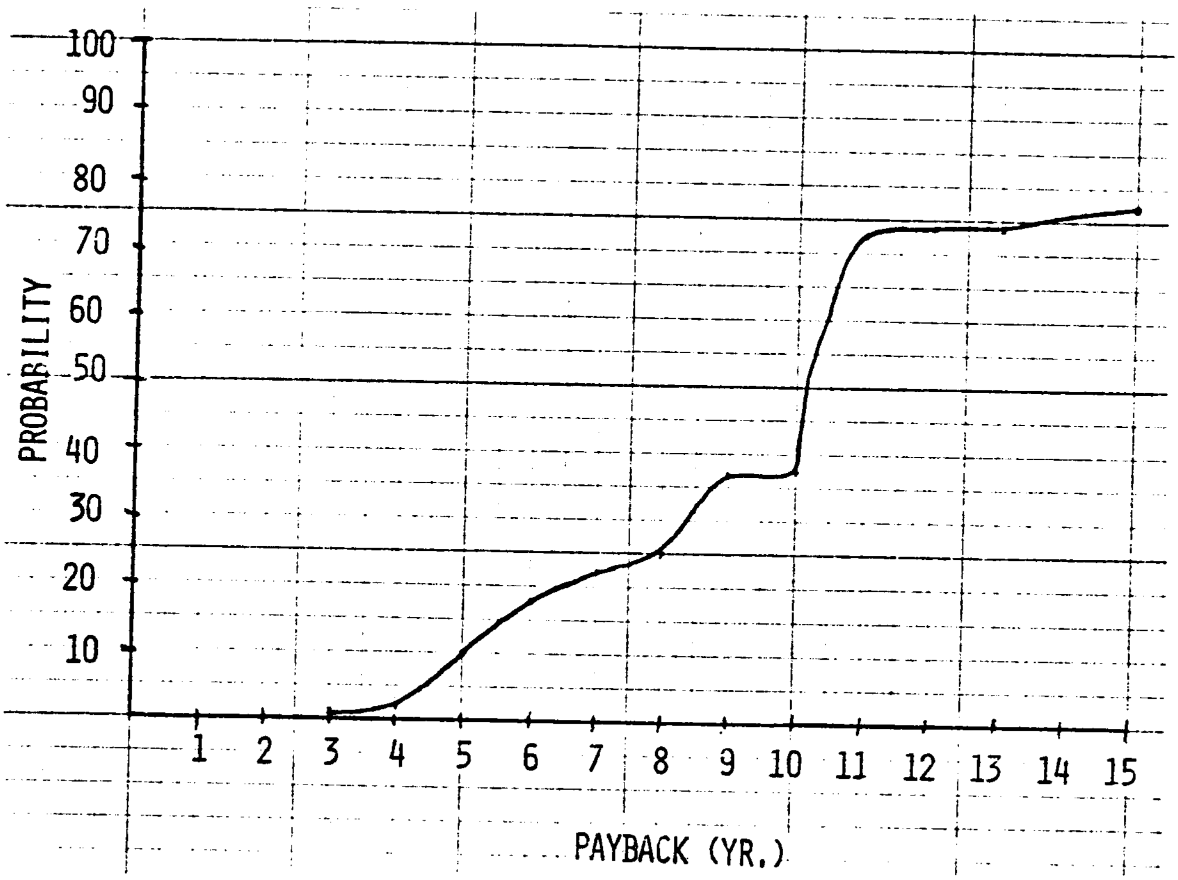


Figure 6.3. Payback versus cumulative probability of the ORNL modular incinerator operating only one shift per working day.

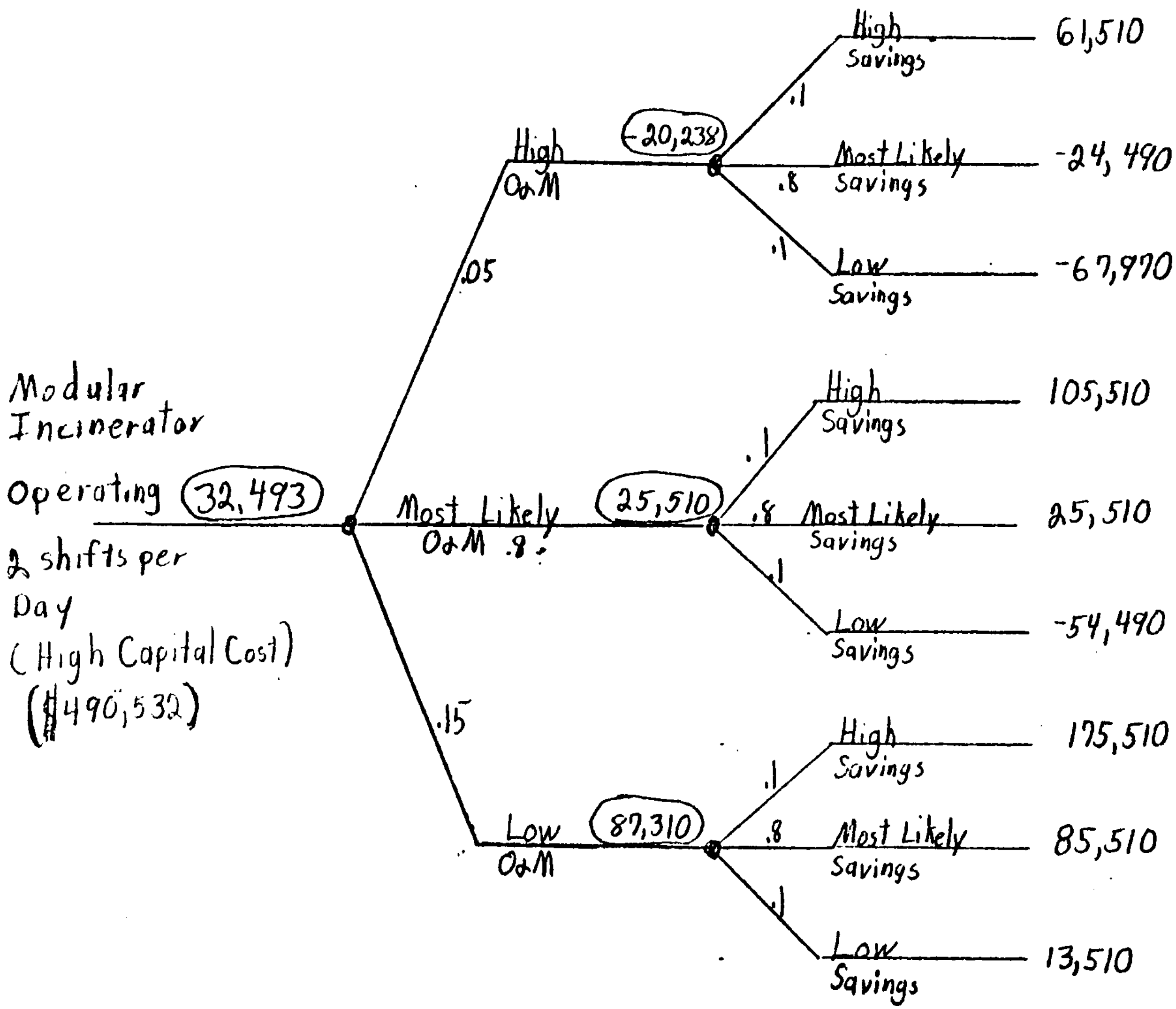


Figure 6.4. Decision branch for the modular incinerator operating two shifts per working day.

annual life cycle cost possibilities of this operating mode are shown on the far right side of the decision tree. Only the high capital cost design $490,532 is assumed in order to have a large enough building to have the tipping floor large enough to handle the delivery of about 14 tons per day.

The expected value is $32,493, which is almost triple the weighted value of a similar facility burning on only one shift per day.

The payback period versus probability of the modular incinerator burning two shifts per working day is shown in Figure 6.5. There is a 87.5% likelihood that the system will payback in less than 10 years.

Figure 6.6 shows the decision branch for the same modular incinerator plant operating with three shifts per working day. The net value of the annual life cycle cost savings calculates at $125,706 which is almost a factor of 10 higher than the modular incinerator facility burning only ORNL's waste during one shift per working day.

The payback period versus probability of the modular incinerator at three shifts per day is shown in Figure 6.7. There is a 90% certainty that the facility will pay back in less than seven years with this design.

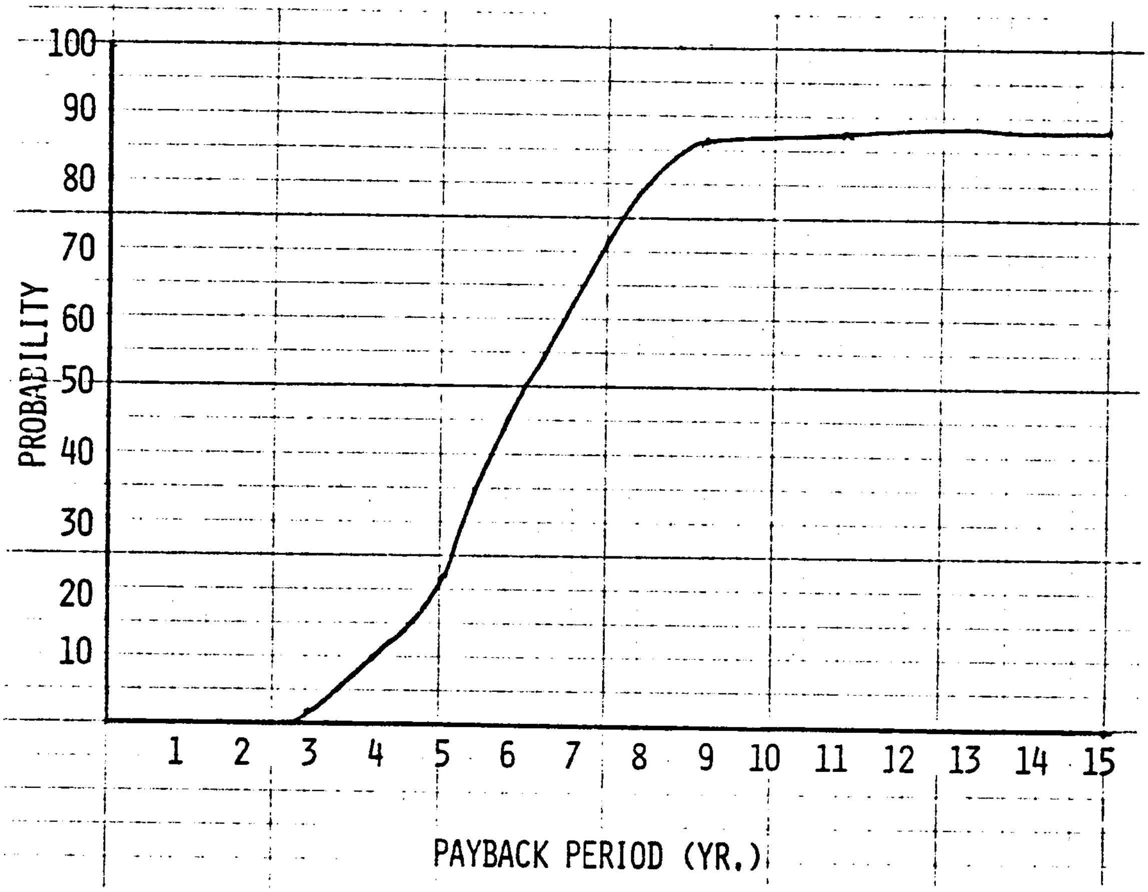


Figure 6.5. Payback period versus cumulative probability of the ORNL modular incinerator operating two shifts per working day.

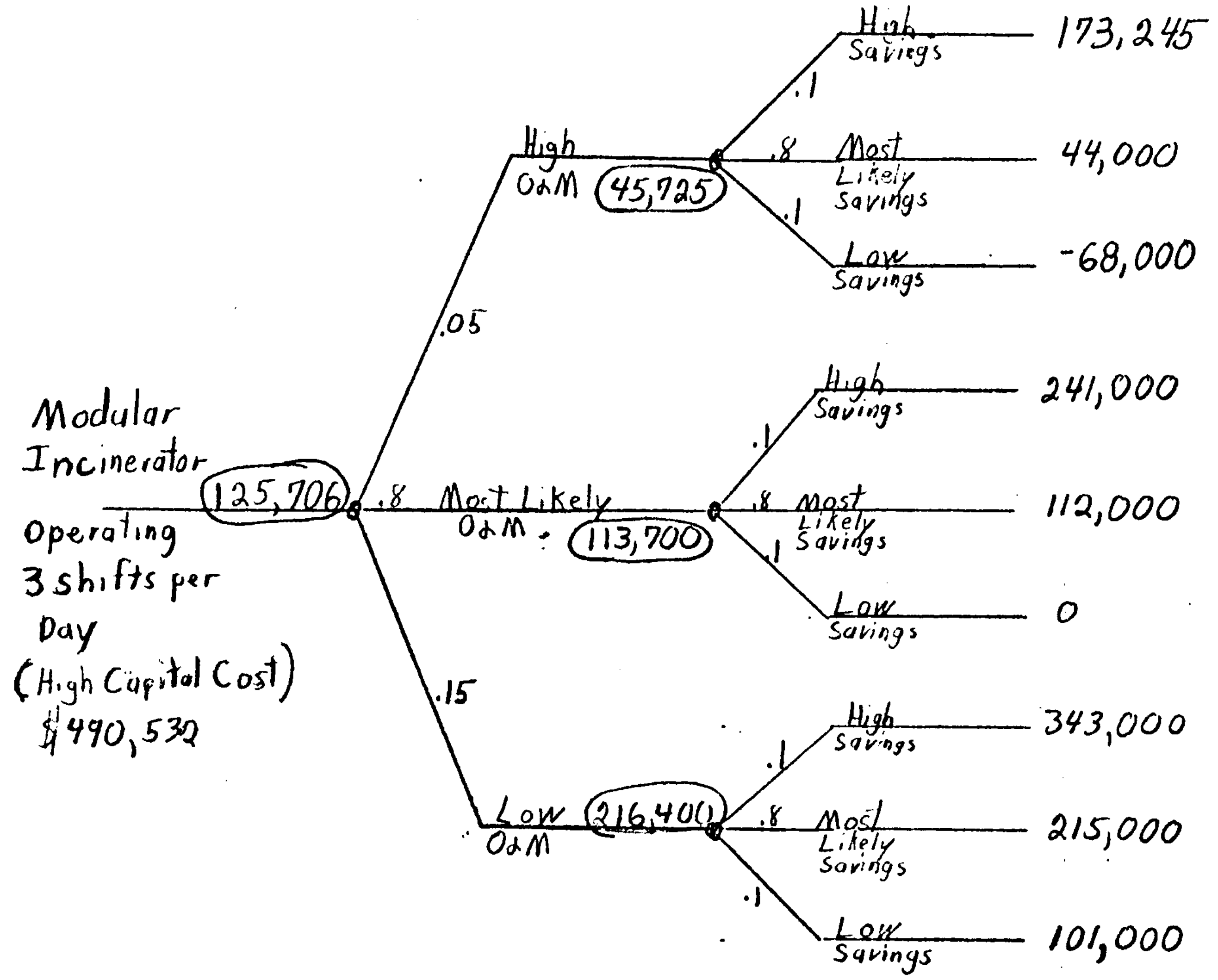


Figure 6.6. Decision branch for the modular incinerator operating three shifts per working day.

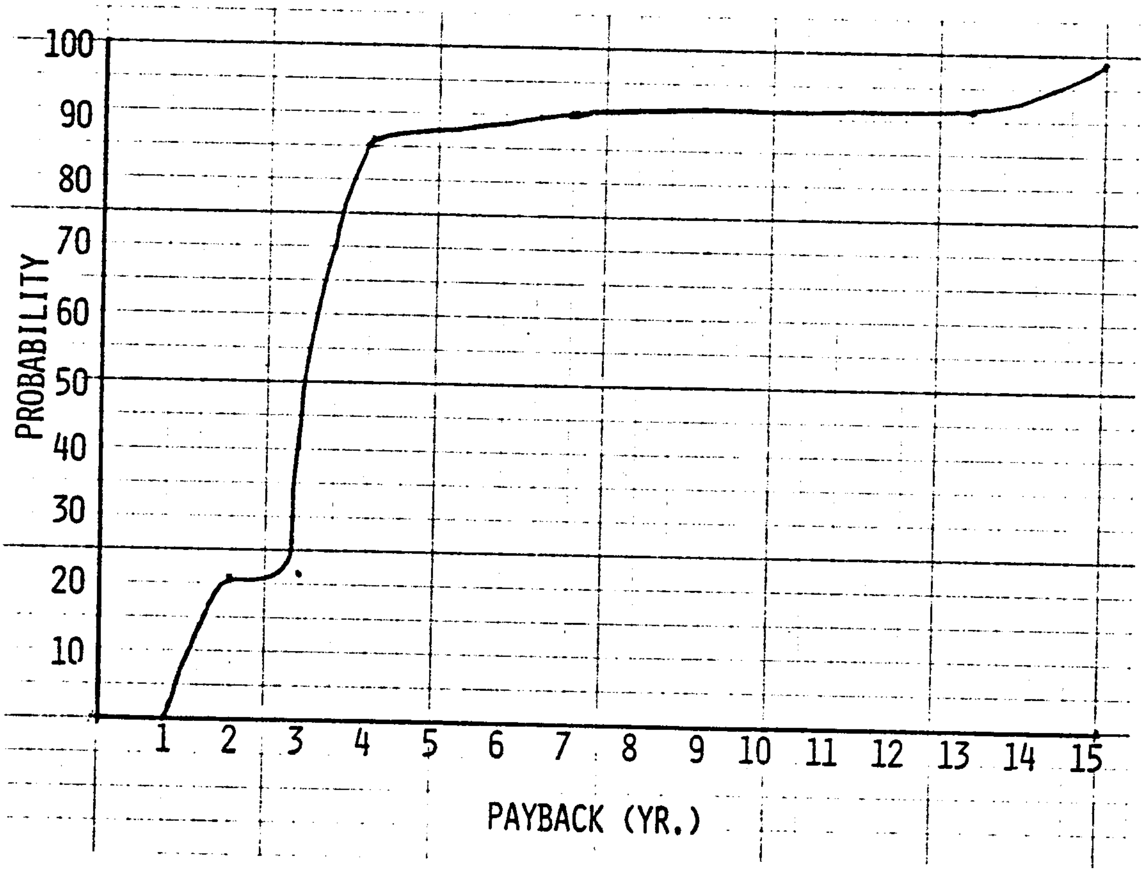


Figure 6.7. Payback period versus cumulative probability of the ORNL modular incinerator operating three shifts per working day.

VII. RECOMMENDATIONS

A. To the Oak Ridge National Laboratory

Visual observation of the refuse content at ORNL suggests that a very high fraction consists of paper and wood. This waste stream offers the Laboratory a very good opportunity to reduce the future nonrenewable energy demand. Besides the dollar savings from displaced oil or electricity, the cost of hauling and landfilling can also be reduced. Presently ORNL refuse is being hauled and landfilled for about $28/ton. Due to the purchase of additional landfilling equipment this cost is expected to be about $39/ton by 1988. The incinerator residue can be landfilled in the "contractors" landfill near the ORNL facility.

Besides modular incinerators the other options considered for ORNL to convert their refuse-to-energy are: expanding the paper recycling program, and refuse derived fuel co-fired in the ORNL steam plant with coal.

The option which has the shortest payback period would be the installation of one modular incinerator at the Building 7601 complex. The incinerator design feed rate should be about 1200-1300 pounds per hour. A single 8-10 hour shift would be adequate to burn all of the ORNL generated refuse.

The future energy needs for experiments in this area of the Laboratory will grow in the next 1-2 years by a factor of about 8. Currently this energy demand is being met by an oil fired boiler with the capacity of

6000 lb/hour of steam. The average energy needs are expected to be about 5000 lb/hr. However the peak energy needs are expected to be 10,000 lb/hour.

With modular incinerator burning refuse for one shift per day there is about a 75% probability that the payback period will be less than 10 years. If the process steam needs are going to be 24 hour loads five days per week the modular incinerator facility could afford to pay for hauling K-25 or Y-12's combustible refuse to the incinerator site and increase to 87.5% the likelihood that the incinerator facility will payback in less than 10 years with two combustion shifts and to a 90% probability of payback in 7 years with three shifts per day. The payback calculations do not account for the capital investment of an additional boiler which will be needed if the peak steam load is to be greater than 6000 lb/hour. A tri-fueled boiler for this facility is estimated at about $350,000.

The specific recommendations to ORNL:

1. Request funding for a modular incinerator facility located to the west of the Building 7601 parking lot. If additional refuse from K-25 and Y-12 will be burned in the incinerator, the capital investment will be around $500,000.

2. Have an ultimate analysis conducted on the ORNL refuse and determine the energy content (see Section V.A.2 of this report).

3. Use only aluminum cans instead of steel in the vending machines and provide aluminum recycle containers near each machine. This will reduce the noncombustibles in the refuse and enhance the incinerator performance.

4. Periodically remind laboratory personnel to keep all noncombustible materials out of the primary waste stream,separate bins for metals, glass and ceramics are already provided.

5. The incinerator facility should leave room for an exhaust gas scrubber down stream from the heat recovery boiler, and a small refuse shredder and magnetic separator near the feed box.

6. The incinerator vendor should be given the refuse analysis results and asked to guarantee auxiliary fuel requirements and emission rates while properly operating the facility. All modular incinerators do not have the capacity to completely modulate the auxiliary fuel in both incinerator chambers. This control feature can drastically affect the auxiliary fuel cost.

7. A number of manufacturers have provided information on the combustion of liquid waste and patholigical waste along with solid waste. A single incinerator facility could be used for the disposal of other waste products generated at ORNL. These opportunities should be considered.

8. The incinerator residue could be disposed of in the "contractors" landfill located near the ORNL site. Residue from the ORNL steam plant is currently landfilled in this facility.

B. To Other Interested Institutions

The waste from universities, large office complexes and research centers may offer an attractive energy conservation opportunity. The waste content from these institutions consists largely of combustible products, which makes the waste easier to handle in resource recovery systems than municipal waste. Another advantage held by institutions is that institutions frequently have control over waste disposal and the heating and cooling services. The future costs and willingness to pay for both refuse disposal and energy are known. This fact eliminates complex contract agreements between two or three parties which frequently are needed in large municipal resource recovery projects.

Four alternatives for resource recovery should be considered in the initial pre-feasibility investigation, paper fiber recycling, modular incineration with heat recovery, refuse derived fuel co-fired with coal and coupling to a district heating system.

Paper recycling programs frequently require additional labor to sort and separate desirable paper products from other materials. The voluntary efforts on the part of employees and students to deliver their waste to recycling stations is only part of the total labor requirement.

The recycled fiber market has contamination requirements which frequently exceed the end product of the waste disposers efforts. The higher the quality of fiber recycled the greater the market value, unfortunately as the market value rises so do the requirements for an uncontaminated product.

Recycling paper saves about 30% more energy than if the paper were incinerated with heat recovery.

Refuse derived fuel co-fired in a coal boiler requires an existing large boiler (>100,000 lb/hr) with moving grates and a waste stream exceeding 100 TPD. Actually a RDF facility is a sophisticated processing plant and should be approached with that perception.

The option of hooking up to a district heating system is attractive, however, very few systems are currently in place. Institutions should discuss with nearby industries, commercial facilities and apartment complexes about the feasibility of supporting a district heating facility. All of the energy needs cannot be met by refuse, however a significant fraction could be met by burning all the institutional waste along with refuse from the neighboring areas.

Modular incinerators appear to be the most attractive option available to institutions for resource recovery.

Besides the initial capital investment annual costs are required to pay for labor and auxiliary fuel. The savings resulting from this investment are from energy displacement, and a reduction in long distance hauling and landfilling.

When determining the major cost for capital, O & M and savings look closely at the annual base energy demand. Will the energy be needed during the summer months as well as winter? Can the facility be run two or three shifts per day instead of only one? The economics look better the closer the plant can be run 24 hours five days per week.

Other significant cost factors are the type of energy being displaced and the cost for labor. Oil and gas are currently more than three times the cost for coal. The labor rates for personnel needed to operate a small modular facility can vary from $10,000 per shift to $70,000. Union restrictions may require at least two people during every operating hour; one boiler operator, one heavy equipment operator.

The analysis procedure described in this report can be followed to determine the cost of modular incineration for your facility. Do not use generic cost factors. Analyze your waste quality and quantity closely. Use actual labor rates for your facility. The decision to invest in institutional waste recovery does have risks like any other investment. The procedure outlined in this report provides a tool to help define those risks and hopefully lead you to proper management of your waste and energy.

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APPENDIX

Table A.1. Composition and analysis of average municipal refuse from studies made by Purdue University*

Component	Percent of all refuse by weight	Moisture (percent by weight)	Analysis (percent dry weight)							Calorific value (Btu/lb)
			Volatile matter	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Noncombustibles[b]	
Rubbish, 64%										
Paper	42.0	10.2	84.6	43.4	5.8	44.3	0.3	0.20	6.0	7,572
Wood	2.4	20.0	84.9	50.5	6.0	42.4	0.2	0.05	1.0	8,613
Grass	4.0	65.0	--	43.3	6.0	41.7	2.2	0.05	6.8	7,693
Brush	1.5	40.0	--	42.5	5.9	41.2	2.0	0.05	8.3	7,900
Greens	1.5	62.0	70.3	40.3	5.6	39.0	2.0	0.05	13.0	7,077
Leaves	5.0	50.0	--	40.5	6.0	45.1	0.2	0.05	8.2	7,096
Leather	0.3	10.0	76.2	60.0	8.0	11.5	10.0	0.40	10.1	8,850
Rubber	0.6	1.2	85.0	77.7	10.4	--	--	2.0	10.0	11,330
Plastics	0.7	2.0	--	60.0	7.2	22.6	--	--	10.2	14,368
Oils, paints	0.8	0.0	--	66.9	9.7	5.2	2.0	--	16.3	13,400
Linoleum	0.1	2.1	65.8	48.1	5.3	18.7	0.1	0.40	27.4	8,310
Rags	0.6	10.0	93.6	55.0	6.6	31.2	4.6	0.13	2.5	7,652
Street sweepings	3.0	20.0	67.4	34.7	4.8	35.2	0.1	0.20	25.0	6,000
Dirt	1.0	3.2	21.2	20.6	2.6	4.0	0.5	0.01	72.3	3,790
Unclassified	0.5	4.0	--	16.6	2.5	18.4	0.05	0.05	62.5	3,000
Food Wastes, 12%										
Garbage	10.0	72.0	53.3	45.0	6.4	28.8	3.3	0.52	16.0	8,484
Fats	2.0	0.0	--	76.7	12.1	11.2	0	0	0	16,700
Noncombustibles, 24%										
Metals	8.0	3.0	0.5	0.8	0.04	0.2	--	--	99.0	124
Glass and ceramics	6.0	2.0	0.4	0.6	0.03	0.1	--	--	99.3	65
Ashes	10.0	10.0	3.0	28.0	0.5	0.8	--	0.5	70.2	4,172
Composite Refuse, as Received										
All refuse	100	20.7	--	28.0	3.5	22.4	0.33	0.16	24.9	6,203

[a]Data from [1].

[b]Ash, metal, glass, and ceramics.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

December 10, 1979

Scientific Energy Engineering, Inc.
1103 Blackstone Building
Jacksonville, Florida 32202

Dear Sir:

I am presently studying the technical, environmental and financial feasibility of burning about 6 tons/per day of Type I waste here at the Oak Ridge National Laboratory. We would like to recover the heat and replace the oil consumption at one of our remote experimental stations. Our steam lines call for 150 psig.

The current preference for the burn schedule is 10 hours/day, 5 days per week. Thus, we need a unit with the capacity of about 1000-1200 lbs. per hour.

Will you please send me your technical description and performance data on your Modular Incinerator along with a cost estimate. Please include the feed system, incinerator, waste heat recovery boiler, stacks and control system.

Any additional information you have on the building, site preparation and equipment installation will help me. Your attention to this request is appreciated.

Yours truly,

Jeff Christian

Jeff Christian
Bldg. 3550
Energy Division

JEC:jt

MATERIAL AND HEAT BALANCE

This section describes the material and heat balance of a modular incinerator burning 6.67 ton/day of ORNL refuse. Table 5.17 (page 85) shows ORNL refuse consists of: 2.21×10^4 lbs per day of combustibles, $.68 \times 10^4$ lbs per day of water, and $.51 \times 10^4$ lbs per day of noncombustibles. The auxiliary fuel required for complete combustion is 7.2×10^6 BTU which is taken from Table 5.14 (page 80). Additional values used in the material and heat balance are shown in Figure A.1. Ultimate element weights are shown in Table A.2.

WEIGHT OF RESIDUE

Inerts are 1,254 lb/day plus inert carbon (assumed to be equal to 2% of inerts or 25 lb/day). The total weight of residue is 1,279 lb/day.

AVAILABLE FREE HYDROGEN AND HYDROGEN IN BOUND WATER

Available free hydrogen and hydrogen in bound water is (based on assumption that 1/8 of the oxygen present is deducted from the total percentage of hydrogen). This correction accounts for the hydrogen in the refuse already combined with oxygen in the form of moisture in the available free hydrogen = $H_2 - 1/8\ O_2$ or 4.1% - (1/8) 30.9 = .337% or 45 lb. Hydrogen in bound water equals the remaining percentage of total hydrogen or 4.1% - .337% = 3.763% or 502 lbs/day. Bound water = 4015.34 + 502= 4517 lbs/day.

To compute the net heat input gross heat input must first be calculated:

Table A.2 Weights of elements in refuse

Element	Conversion	Pounds per day
Carbon	$0.31 \times 13{,}340$	4,135
Hydrogen	$0.41 \times 13{,}340$	547
Oxygen	$0.301 \times 13{,}340$	4,015.34
Nitrogen	$0.003 \times 13{,}340$	40
Sulfur	$0.001 \times 13{,}340$	13.3
Water	$0.25 \times 13{,}340$	3,335
Inerts	$0.094 \times 13{,}340$	1,254

$= (6{,}489\ BTU/lb)\ (13{,}340\ lb/day)$

$= 86.6 \times 10^6\ BTU/day$

Heat input lost to unburned carbon:

$25\ lb/day \quad (14{,}093\ BTU/lb)$

$= .35 \quad 10 \quad BTU/day$

net heat input

$86.6 \times 10^6 - .35 \times 10^6 = 86.25 \times 10^6\ BTU/day$

$86.25 \times 10^6 - \underset{\text{(auxiliary fuel)}}{7.2 \times 10^6} = 79. \times 10^6\ BTU/day$

LATENT HEAT LOSSES

inherent moisture $= (3335\ lb/day)\ (1040\ BTU/lb)$

$= 3.47 \times 10^6\ BTU/day$

moisture in bound water $= (4517\ lbs/day)\ (1040\ BTU/lb)$

$= 4.7 \times 10^6\ BTU/day$

moisture from oxidation of hydrogen

$\frac{9\ lb\ H_2O}{1\ lb\ H}\ (45\ lb/day)\ (1040\ BTU/lb$

$= .42 \quad 10^6\ BTU\ day$

REACTOR LOSSES

Radiation loss $= .05\ BTU/BTU\ (86.6 \times 10^6\ BTU/day)$

$= 4.33 \times 10^6$

Sensible heat in residue

$(1279\ lb/day)\ [.25\ BTU/lb - °F\ (800\text{-}80°F)]$

$= 0.23 \times 10^6\ BTU/day$

TOTAL HEAT LOSSES

$3.47 \times 10^6 + 4.7 \times 10^6 + .42 \times 10^6 + 4.33 \times 10^6 + 0.23 \times 10^6 + .35 \times 10^6 = 13.5 \times 10^6$.

1.	Lower heating value of refuse	6,489 Btu
2.	Unburned carbon in residue	2%
3.	Temperature of incoming air	80°F
4.	Temperature of grate residue	800°F
5.	Specific heat of residue	0.25 Btu/lb
6.	Latent heat of water	1,040 Btu/lb
7.	Radiant heat loss (Ref. 49)	0.50 Btu/lb

8. All oxygen in solid waste is bound as water
9. Theoretical air requirements based on stoichimetry:
   a. carbon $C + O_2 \rightarrow CO_2$

   $$\frac{1}{0.2315} \times \frac{32}{12} = 11.52 \text{ lb air/lb carbon}$$

   b. hydrogen $(2H_2 + O^2 \rightarrow 2H_2O)$

   $$\frac{1}{0.2315} \times \frac{32}{4} = 34.56 \text{ lb air/lb hydrogen}$$

   c. sulfur $(S + O^2 \rightarrow SO_2)$

   $$\frac{1}{0.2315} \times \frac{32}{32.1} = 4.31 \text{ lb air/lb sulfur}$$

10.	Heating value of carbon	14,093 Btu/lb
11.	Moisture in the combustion air	1%
12.	Lower heating value of auxiliary fuel	138,000 Btu/lb

Figure A.1. Assumptions used in the material and heat balance calculations.

VITA

Jeffrey E. Christian was born in Merrill, Wisconsin on January 16, 1952. He attended high school at Premontre in Green Bay, Wisconsin and graduated in the top 5% of his class in May 1970. He received his Bachelor of Engineering from the University of Wisconsin graduating number two in the Industrial Engineering Department in 1974.

While attending the University of Wisconsin, he worked for Wisconsin Public Service during the summer. His major accomplishments during his term with this electric utility was the preparation of the first environmental impact statement prepared on an electric transmission line in the State of Wisconsin.

In 1974, he accepted a position at the Oak Ridge National Laboratory in the newly formed Energy Division. The author's responsibilities in the Community Systems Group have resulted in almost two dozen reports involving system analysis, market penetration, model development and technical evaluation including:

1. W.R. Mixon et al. "Technology Assessment of Modular Integrated Utility Systems," ORNL/HUD/MIUS-25, December 1976.

2. W.R. Mixon, J.E. Christian et al. "Energy and Cost Comparisons of Fuel Cell Total Energy Systems and Conventional Building Energy Systems" ORNL/CON-36, March 1979.

3. J.E. Christian, Gas-Steam Turbine Combined Cycle Power Plants, ANL/CES/TE, April 1978.

4. J.E. Christian, Central Cooling-Absortive Chillers, ANL/CES/TE 77-8, August 1977.

5. J.E. Christina, W.L. Jackson, ORNL Community Energy Systems Analysis Program (CESAP) Description and Users Manual, ORNL/TM-7225, February 1980.

The author also writes and publishes monthly a four page newsletter for the Energy Conservation Society.