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American Combustion Pyretron Destruction System

Applications Analysis Report

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U.S. Environmental Protection Agency
Cincinnati, OH 45268

Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations which are designed to provide engineering and cost data on selected technologies.

This project consists of an analysis of American Combustion's Pyretron oxygen enhanced burner system. The technology demonstration took place at U.S. EPA's Combustion Research Facility in Jefferson, Arkansas, and used a mixture of decanter tank tar sludge from coking operations (RCRA listed waste K087) and soil excavated from the Stringfellow Superfund site in Riverside, California. The demonstration effort was directed at obtaining information on the performance and cost of the process for use in assessments at other sites. Documentation will consist of two reports. The Technology Evaluation Report (EPA/540/5-89/005) describes the field activities and laboratory results. This Applications Analysis provides an interpretation of available data and discusses the potential applicability of the technology.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA, 22161, (702) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at l-800-424-9346 or 382-3000 in Washington, D.C. to inquire about the availability of other reports.

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Abstract

Incineration is widely used to clean up Superfund sites. Modifications which improve the efficiency with which waste can be incinerated are therefore of interest to EPA. Oxygen/air burners are of interest because their installation on conventional incinerators can allow for significant increases in waste feedrate and on-line time. It is for this reason that an oxygen/air burner was evaluated in the SITE program.

The Pyretron Thermal Destruction System is an innovative oxygen enhanced burner system which can be used in conjunction with a conventional incinerator to treat Superfund site wastes amenable to treatment via incineration. The major advantage to the Superfund program of using the Pyretron, or other oxygen/air burners, is that the waste feedrate of low BTU content solids and, under some circumstances, high BTU content solids can be significantly increased. The throughput rate was doubled in a test incinerator using the Pyretron to treat waste with a heating value of 24.1 MJ/kg (10,400 BTU/lb) during the demonstration. This was achieved only with the injection of water into the kiln to provide additional heat absorption capacity. While water injection was successful in this case, it may not be practical for wastes with heating values significantly above that used during the SITE demonstration. Its usefullness in treating low heating value wastes may make the Pyretron applicable to many wastes found at Superfund sites.

The Pyretron system may offer economic advantages over conventional incineration in treating low heating value wastes in situations where auxiliary fuel and operating labor costs are relatively high and delivered oxygen costs are relatively low. This is because, in these situations, throughput increases would offset the added costs of oxygen and capital equipment associated with the use of this technology. Economic advantages do not exist in reverse situations (relatively low fuel and operating labor costs/relatively high delivered oxygen costs). The economic advantage results from fuel savings and increased waste throughput capabilities, offset by process equipment and oxygen costs. Since the Pyretron is a burner system and therefore only part of an incineration system, regulatory requirements, environmental monitoring requirements, material handling requirements, and personnel issues applicable to a Pyretron system application are not measurably different than those applicable to the use of a conventional burner mounted on a transportable incinerator.

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This report was prepared under the direction and coordination of Laurel J. Staley, EPA SITE Program Manager in the Risk Reduction Engineering Laboratory -- Cincinnati, Ohio. Contributors and reviewers for this report were Gordon Evans, Steven James, Robert Olexsey, Robert Stenburg, Gregory Carroll, John Kingscott, Richard Valentinetti, and Ronald Hill of the USEPA and Mark Zwecker of American Combustion.

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Section 1
Executive Summary

The Pyretron Thermal Destruction System is an innovative burner system employing dynamic oxygen enhancement of the combustion process. The system is designed to be used in conjunction with a conventional transportable or fixed rotary kiln incinerator and is intended to increase the efficiency of conventional incineration.

Relatively little data exist for evaluation of the technology besides information from the SITE demonstration which was conducted at the EPA's Combustion Research Facility. An additional study was conducted by the EPA's Air and Energy Engineering Research Laboratory (AEERL). The results of this study are summarized in Appendix D of this report. The conclusions of this Applications Analysis are:

1. The Pyretron burner system is a viable technology for treating Superfund waste.

2. The system is capable of doubling the capacity of a conventional rotary kiln incinerator. The greatest capacity increases will occur for wastes with low heating value.

3. Increased capacity can result in cost savings. This will be primarily affected by labor cost, length of the cleanup, and the local costs of oxygen and fuel.

4. In situations in which particulate carryover resulting from excessive gas volume causes operational problems, the Pyretron may increase reliability. This is because, by replacing some of the combustion air with oxygen, using the Pyretron reduces combustion gas volume.

5. Data from the SITE demonstration do not show a statistically significant difference in the level or frequency of transient emissions. An average of 16 transients/test were observed during air-only operation. Only 6 transients/test were observed during oxygen-enriched operation.

The Pyretron system can be used to treat any waste amenable to treatment via conventional incineration. However, its primary advantage, increased throughput, can best be realized in the treatment of solid wastes with relatively low heating value. This is because the major factor limiting throughput for low heating value wastes is the volume of combustion gas required for incineration of a unit volume of waste. Since oxygen enhancement reduces combustion volume by displacing diluent nitrogen in the combustion air stream, it significantly reduces the volume of combustion gas required, thus allowing throughput increases for this type of waste. For this reason, it. may prove useful in the treatment of Superfund site wastes.

American Combustion, Inc. (ACI) states that Pyretron system offers three advantages over conventional incineration. These are:

- The Pyretron system will be capable of reducing the magnitude of transient high levels of carbon monoxide (CO), unburned hydrocarbon, and soot ("puffs") that can occur with repeated batch charging of a high heat content waste to a rotary kiln.

- The Pyretron system will allow increased waste feedrate to the kiln while still achieving the hazardous waste incinerator performance standards for POHC destruction and removal efficiency (DRE) and particulate emissions.

- The Pyretron system is more economical than conventional incineration.

These claims were evaluated during the SITE demonstration of the Pyretron at the EPA Combustion Research Facility (CRF) which occurred from November 1987 to January 1988. The demonstration tests were conducted using waste material excavated from the Stringfellow Superfund site near Riverside, California. The Stringfellow soil was combined with a high heating value listed hazardous waste, K087, which is decanter tank tar sludge from coking operations. The objective of the demonstration tests was to provide the data to evaluate the three ACI claims regarding the Pyretron system noted above.

The Pyretron system designed for use in the SITE demonstration consists of two burners, one installed in the primary combustion chamber (kiln) and one installed in the afterburner; valve trains for supplying these burners with controllable flows of auxiliary fuel, oxygen, and air; a computerized process control system; an oxygen supply system; and a kiln water injection system. The Pyretron burners use a proprietary parallel combustion approach based upon the independent introduction of either air, oxygen-enriched air or pure oxygen.

With respect to the first ACI claim, the demonstration test results were inconclusive. This claim was to be evaluated through a time series comparison of the transients observed during oxygen-enhanced and air-only operation. Insufficient numbers of transients were generated to complete this analysis. During the course of each 8-hour test conducted during the SITE demonstration, an averae of 16 transients/test occurred during air only operation. A total of 6 transients/test occurred during oxygen enriched operation. These data are described in more detail in the Technology Evaluation Report on the Pyretron.This may have been caused, in part, by the non-uniform nature of the waste feed used. Non-uniformity of this type is typical of Superfund waste streams and may make it difficult to evaluate transient performance in the field. The effect of the Pyretron on transient emissions was studied by the USEPA's Air and Energy Engineering Research Laboratory (AEERL) using simulated waste batch fed to a rotary kiln simulator. The results of that study, summarized in Appendix D, indicate that oxygen enhancement may worsen transient emissions.

With respect to the second AC1 claim, demonstration test results clearly indicated that 99.99 percent POHC DRE was achieved with the Pyretron system at double the waste feedrate possible under conventional operation. Water injection was required, however, to accomplish the throughput increases. This is because the nitrogen that is displaced when oxygen is added to the combustion air stream is needed as a heat sink when high heating value wastes are incinerated. Without that nitrogen, a substitute heat sink must be used. Water injection adequately served that purpose during the demonstration. However, this may not be practical in all situations. In addition, particulate emissions of significantly less than 180 mg/dscm at 7 percent O_2 were measured. Finally, the solid and liquid residues generated during the SITE demonstration were contaminant free.

With respect to the third ACI claim, cost estimates show that use of the Pyretron system in treating a waste with characteristics similar to the waste material used during the demonstration tests can be less costly than conventional incineration in situations where auxiliary fuel and operating labor costs are relatively high, and oxygen costs are relatively low. The analysis indicates a potential for substantial savings under favorable circumstances. for the evaluation case assumed, treatment of 4,480 tonnes (4,930 tons) of waste with characteristics similar to the material incinerated during the demonstration test program, Pyretron system treatment costs were $3l/tonne ($28/ton) less than conventional incineration treatment costs. The wastes employed in the demonstration tests had relatively high heating value (24.1 MJ/kg (10,400 Btu/lb)).

Section 2
Introduction

2.1 The SITE Program

In 1986, the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its third year, SITE is helping to provide the treatment technologies necessary to implement new federal and state cleanup standards aimed at permanent remedies, rather than quick fixes. The SITE Program is composed of three major elements: the Demonstration Program, the Emerging Technologies Program, and the Measurement and Monitoring Technologies Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. To date, the demonstration projects have not involved funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also will accept proposals at any time when a developer has a treatment project scheduled with Superfund waste. To qualify for the program, a new technology must be at the pilot *or* full scale and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA Regional Offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports, which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of a system ready for field demonstration. The third component of the SITE Program, the Measurement and Monitoring Technologies program, provides assistance in the development and demonstration of innovative technologies to better characterize Superfund sites.

2.2 SITE Program Reports

The analysis of technologies participating in the Demonstration Program is contained in two documents, the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report contains a comprehensive description of the demonstration sponsored by the SITE program and its results. This report gives a detailed description of the technology, the site and waste used for the demonstration, sampling and analysis during the test, and the data generated.

The purpose of the Applications Analysis Report is to estimate the Superfund applications and costs of a technology based on all available data. This report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology. Costs of the technology for different applications are estimated based on available data on pilot- and full scale applications. The report discusses the factors, such as site and waste characteristics, that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic wastes, or may include performance data on actual wastes treated at the pilot or full scale. In addition, there are limits to conclusions regarding Superfund applications that can be drawn from a single field demonstration. A successful field demonstration does not necessarily assure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Superfund cleanups and represents a critical step in the development and commercialization of the treatment technology.

2.3 Key Contacts

For more information on the demonstration of the Pyretron technology, please contact:

1. EPA project manager concerning the SITE demonstration:

    Ms. Laurel Staley
    U.S. Environmental Protection Agency
    Risk Reduction Engineering Laboratory
    26 W. Martin Luther King Jr. Drive
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2. Vendor concerning the process

    Mr. Mark Zwecker
    American Combustion, Incorporated
    2985 Gateway Drive
    Norcross, Georgia **30071**
    (404)662-8156

3. EPA project manager concerning the Combustion Research Facility

    Mr. Robert Thurnau
    U.S. Environmental Protection Agency
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    (513) 569-7429

There are other vendors of oxygen/air burner systems. One such system was used in the EPA sponsored cleanup of dioxin contaminated soil in Southwest Missouri. Information on the performance of this burner is presented in Appendix D.

Section 3
Technology Applications Analysis

Incineration is currently a significant Superfund SITE remediation option. For example, incineration/thermal destruction was selected as the source control remediation for 26 of 76 (or roughly one third) of the Records of Decision signed in 1988.(l) For remediations using on-site incineration, the decontamination of soils and sludges is of predominant interest. While many feed-related factors affect incinerator feed rates and reliability, the particle size distribution, heat content, and moisture content of the soils and sludges have distinct effects. Oxygen enhance mentor pure oxygen burners used on on-site incinerators are of interest to the Superfund program in that they offer the potential to increase both feed rates and equipment reliability, thus lowering costs, for solid feeds having a wide variety of particle sizes, heat values, and moisture contents.

The Pyretron system is an air/oxygen burner that can be used with any incinerator considered for Superfund site waste treatment provided certain implementation criteria are satisfied. This section discusses the general applicability of the technology and describes possible constraints to its application.

3.1 Introduction

This section of the report addresses the applicability of the process to varying potential feedstocks based upon the results obtained from the SITE Demonstration Test and the study of the Pyretron system at the EPA's Air and Energy Engineering Research Laboratory (AEERL) in Research Triangle Park, North Carolina.(2) In addition, some information is available from an oxygen burner on EPA's Mobile Incineration System at the Denney Farm site in Missouri. Neither study was done under the SITE program and neither will be discussed in detail. They will only be used to support conclusions drawn during the demonstration. Both studies are summarized in Appendix D.

Following are the overall conclusions being drawn about the Pyretron based upon the results of the SITE demonstration. Appendix C provides a summary and discussion of the results of the SITE demonstration. These results are explained in more detail in the Technology Evaluation Report.(3)

3.2 Conclusions

The conclusions drawn from reviewing the data on the Pyretron system are as follows.

1. Using the Pyretron system with oxygen enhancement can enable significant waste throughput increases to be achieved. Incinerator heat release capacity limits these throughput increases for wastes with very high heating value. For wastes with moderately high heating value, water injection can provide sufficient heat absorption capacity to enable significant throughput increases to be achieved. For wastes with low heating value, throughput increases should be readily achieved since they would not be limited by the heat release capacity of the incinerator. These results are supported by experience at another hazardous waste incinerator that made use of oxygen enhancement. Experience with this device is summarized in Appendix D.

2. Because of the above mentioned throughput increases, the Pyretron system can make hazardous waste incineration more economical in situations in which the throughput increases are large, the operating and fuel costs are high and oxygen costs are relatively low. Since the Pyretron is a burner system and therefore only a part of an incineration system the capital costs associated with the Pyretron system are expected to be small relative to the costs of the entire incinerator. Operating and utility costs per ton of waste processed are expected to be reduced most by use of the Pyretron in situations in which throughput increases are readily achievable.

This result is supported by experience at another hazardous waste incinerator that has employed oxygen enhancement (see Appendix D).

3. The results of the SITE demonstration do not show that the Pyretron system can reduce transient emissions. Data obtained from the demonstration do not show a statistically significant difference between the frequency and level of transient emissions observed with air-only and oxygen

enhanced operation. During air-only operation, an average of 16 spikes/test were observed. Only 6 spikes/test were observed for oxygen-enhanced operation. During the SITE demonstration, transient emissions, contrary to expectation, were not an operational problem which significantly hindered operation of the incinerator. Waste throughput was limited much more by the heat release capacity of the incinerator at the CRF than by the onset of transient emissions. The heat release limitations were overcome by water injection.

4. Levels of NO_x observed during the SITE demonstration were roughly an order of magnitude higher when oxygen enhancement was used (see Appendix C, Table C-4). These results are consistent with those obtained from the study at AEERL on a smaller version of the Pyretron. Those studies also found very high Levels of NO_x and indicated that high flame temperature is the predominant factor in producing high levels of NO_x emissions (see Appendix D). Further design and development of the Pyretron focusing on reducing the flame temperature, may alleviate this problem. See Appendix C, of the Technology Evaluation Report (3) for further details.

3.3 Site Characteristics Suitable for Pyretron System Implementation

3.3.1 Size of Operation

The Pyretron is a burner system incorporating oxygen enhancement of the combustion process. It is available in several size ranges from 0.29 to 73 MW (1 to 250 MMBtu/hr) heat input. Thus, it can be retrofitted to a wide variety of incinerator sizes.

The physical size of an incineration treatment process using the Pyretron system would be essentially the same as an incinerator with conventional burners. Thus, most of the candidate transportable incinerators for using the Pyretron systems are expected to be in the 9 to 15 MW (30 to 50 MMBtu/hr range), although some new systems are being built with capacities up to 23 MW (80 MMBtu/hr). Process equipment and other site requirements such as laboratory support, sample transportation, materials storage for processing, chemical analysis, decontamination, waste storage and removal, and other auxiliary process and equipment requirements would be the same for the Pyretron system as for conventional incineration.

The only addition to physical treatment size required by Pyretron system would be an oxygen supply system and a water supply system. Trailer-mounted liquid oxygen tanks with evaporators are available and could be used instead of a fixed oxygen supply tank. The water supply system to allow rotary kiln temperature control would not add significantly to the size of the complete incinerator system.

Waste treatment rates for transportable incinerators are generally in the 0.9 to 9.1 tonnes/hr (1 to 10 ton/hr) range. For a typical contaminated soil or sludge with specific gravity of about 2, this would translate to a treatment capacity of between 3,060 and 30,600 m^3/yr (4,000 and 40,000 yd^3/yr). For illustration, 4,050 m^2 (1 acre) excavated to a depth of 0.91 m (3 ft) would contain 11,100 m^3 (14,500 yd^3). Thus, one or more years would be required to treat expected Superfund site waste volumes.

For wastes with relatively low heating value (e.g. common soil with 20% moisture and less than one percent organic contamination), significantly increased waste throughput capability could be realized with the Pyretron system for the following reason. Throughput limitations for low heating value wastes are based on combustion gas volume limitations. Combustion gas is primarily comprised of nitrogen from the air (4 parts nitrogen to 1 part oxygen) and water vapor from soil moisture and from the combustion reactions that take place. If the combustion gas volume is too high, excessive gas velocities result. These velocities lead to operational problems such as particle entrainment (in the case of soils) and loss of gas residence time. When oxygen is added to the combustion air stream and displaces nitrogen, this reduces the combustion gas volume alleviating the above operational problems and making it possible to operate at higher feedrates and with less downtime.

For wastes with higher heating values, increased throughput with the Pyretron is still possible, although not as readily achieved as with lower heating value wastes. This is because, if the organic content and resulting heating value of the feed is too high, throughput will be limited by the heat release limitations of the incinerator. Control of the kiln temperature can become difficult at elevated feed rates and, as a result, feed capacity can be restricted.

Water injection can increase kiln capacity under these conditions because water provides a very effective heat sink. However, the resulting water vapor increases the combustion gas volume and decreases the secondary combustion chamber residence time, thus limiting the effectiveness of water injection as a means of achieving a throughput increases.

3.3.2 Pathways for Off-site Migration

The pathways for offsite migration of wastes are the same for Pyretron incineration as for conventional incineration. Wastes include effluent from the air pollution control system employed (blowdown from a wet scrubber or particulate and/or spent dry sorbent from a dry scrubber system). Offsite migration of stack emissions can also occur. The Pyretron system has a potential for emitting higher NO_x levels than conventional burners, although it may be possible to address this problem by designing the system for low-NO_x operation.

3.3.3 Physical Site Characteristics

The requirements on general site characteristics such as topography, geotechnical features, site access, hydrology, and climate requirements for a Pyretron application are the same as for conventional incineration.

The utility requirements include such conventional incineration needs as electricity and water. In addition, the Pyretron thermal destruction system requires an oxygen supply system. Trailer-mounted liquid oxygen tanks with evaporators are available. In addition, safety codes affect the installation and handling of oxygen.

The site security requirements are the same as for conventional incineration with added concern for the liquid oxygen tank. Flammables and fire sources must be kept at a reasonable distance to prevent increased risk of fire or explosion.

3.4 Regulatory Requirements

Section 121 of CERCLA requires that, subject to specified exceptions, remedial actions must be undertaken in compliance with applicable or relevant and appropriate requirements (ARARs), Federal laws, and more stringent promulgated State laws (in response to releases or threats of releases of hazardous substances or pollutants or contaminants) as may be necessary to protect human health and the environment.

The ARARs which must be followed in incinerating Superfund waste onsite are outlined in the Interim Guidance on Compliance with ARAR, Federal Register, Vol. 52, pp. 32496 et seq. These are:

- Performance-, Design-, or Action-Specific Requirements. Examples include RCRA incineration standards and Clean Water Act pretreatment standards for discharges to POTWs. These requirements are triggered by the particular remedial activity selected to clean a site.

- Ambient/Chemical-Specific Requirements. These set health-risk-based concentration limits based on pollutants/contaminants, e.g., emissions limits and ambient air quality standards (NAAQS). The most stringent ARAR must be complied with.

- Locational Requirements. These set restrictions on activities because of site location and environs, e.g., Federal/State siting laws.

Superfund regulations in 40 CFR 300.68(a)(3) state that Federal, State, and local permits are not required for fund-financed remedial actions or remedial actions taken pursuant to Federal action under Section 106 of CERCLA. However, several states such as Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New Jersey, New York, Pennsylvania, and California have independent state Superfund laws that may be more stringent than the Federal laws, and thereby have primacy. In addition, some state and local authorities such as the California South Coast Air Quality Management District (SCAQMD) and Department of Health Services (DHS) insist that all potential Superfund site incinerators must be permitted like any other incinerator -- in apparent disagreement with the Federal regulation cited above. Deployment of Pyretron systems will therefore be affected by three main levels of regulation:

- Federal EPA incinerator, air, and water pollution regulations

- State incinerator, air, and water pollution rules

- Local regulations, particularly Air Quality Management District (AQMD) requirements

These regulations affect all incinerators -- conventional or with the Pyretron system -- and the following discussion focuses on the particular aspects that are important to the Pyretron system.

3 . 4 . 1 Federal EPA Regulations

3.4.1.1 ARARs

As discussed in the interim guidance document on compliance with ARAR (52FR32496), a requirement under other environmental laws may either be “applicable” or “relevant and appropriate” to a remedial action, but not both. A two-tier test may be applied: first, to determine whether a given requirement is applicable; then, if it is not applicable, to determine whether it is nevertheless relevant and appropriate.

“Applicable requirements” means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Superfund site.

“Applicability” implies that the remedial action or the circumstances at the site satisfy all of the jurisdictional prerequisites of a requirement. For example, the hazardous waste incinerator regulations would apply for incinerators operating at Superfund sites containing listed or characteristic hazardous wastes.

"Relevant and appropriate requirements" means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Superfund site, address problems or situations sufficiently similar to those encountered at the Superfund site that their use is well suited to the particular site. For example, if a Superfund site contained no specifically listed or characteristic hazardous wastes, the hazardous waste incinerator regulations might still be considered relevant and appropriate.

3.4.1.2 *Incinerator Regulations*

The federal hazardous waste incinerator regulations would be considered either "applicable" or "relevant and appropriate" to the incineration treatment of a Superfund site waste via either conventional incineration or use of the Pyretron system. These regulations establish hazardous waste incineration performance standards as detailed in 40 CFR 264 subpart 0. These rules are being revised, and the new proposed regulations are due to be published in 1989. These regulations are applicable to incineration of hazardous wastes at a Superfund site, and may be deemed relevant and appropriate to the incineration of some wastes that are not specifically listed in 40 CRF Part 261.

The important incinerator regulations for both conventional incineration as well as Pyretron system deployment are:

- Performance standards: Section 264.343
- Operating requirements: Section 264.345
- Monitoring and inspections: Section 264.347

Under the current version of these regulations, an incinerator (with or without the Pyretron system) will be required to:

- Achieve a DRE of 99.99 percent for each principal organic hazardous constituent (POHC) in the waste feed
- Control HCl emissions to the larger of 1.8 kg/hr (4 lb/hr) or 1 percent of the stack HCl prior to entering any pollution control equipment
- Limit particulate emissions to less than 180 mg/dscm (0.08 grains/dscf), corrected to 7 percent 0_2
- Continuously monitor combustion temperature, waste feedrate and an indicator of combustion gas velocity
- Continuously monitor CO in the stack exhaust gas

As discussed in Appendix C, the Pyretron system demonstration program established compliance with these requirements.

3.4.1.3 Water Regulations

Provisions of the Safe Drinking Water Act also apply to remediation of Superfund sites. CERCLA Section 121(d)(2)(A) and (B) explicitly mention three kinds of surface water or groundwater standards with which compliance is potentially required -- maximum contaminant level goals (MCLGs), Federal water quality criteria (FWQC), and alternate concentration limits (ACLs) where human exposure is to be limited. This section describes these requirements and how they may be applied to Superfund remedial actions. The guidance is based on Federal requirements and policies; more stringent, promulgated state requirements (such as a stricter classification scheme for groundwater) may result in application of even stricter standards than those specified in Federal regulations.

3.4.2 State and Local Regulations

In addition to the Federal regulations noted in Section 3.4.1, the Federal Prevention of Significant Deterioration (PSD) and New Source Review (NSR) regulations promulgated under the Clean Air Act and administered by the states will impact Pyretron system deployment through the emissions monitoring control and process requirements or through the permitting process in areas that require permits to install and operate. In addition to these, there are several local regulations that govern incinerator operations because incinerators are combustion devices (emissions sources) and each incineration application is site-specific. Many of these state and local emissions regulations are more stringent than EPA rules and the cognizant regulatory agencies have primacy. Pressure could, therefore, be anticipated from state and local authorities in relation to NO_x emissions, for example. (The higher flame temperatures possible with the Pyretron technology could increase the formation and emission of NO_x from air nitrogen and nitrogenous wastes. This could contribute to the regulatory pressure for NO_x control.)

There are six basic sources of potential regulations on Pyretron system deployment at the state and local level:

- Permits to construct/operate

  -Best available control technology (BACT) triggers for stationary sources or units
  -Cumulative or offset triggers

- New Source Review

  -BACT trigger levels and BACT designations
  -Offset triggers

- Prevention of Significant Deterioration

  -BACT controls
  -Increment limitations

- General prohibitions on emissions levels

- Source-specific standards on emissions levels (currently none, but the mechanism exists)

- Nuisance rules

Discharge permits may also be required from the regional water quality board. Discharge permits would apply equally to Pyretron applications and conventional incinerators.

The major regulatory requirements will include permits to install and operate as well as NSWPSD reviews as appropriate. Many states such as California, New Jersey, Pennsylvania, Ohio, New York, Texas, and Virginia will require some form of NO_x control and/or monitoring for CO, unburned hydrocarbon (UHC), and NO_x. These regulations will apply to all incinerators, including those fitted with the Pyretron system. The required control will be a BACT, reasonably available control technology (RACT), or lowest achievable emission rate (LAER) control, and will range from exemptions for short burns of small amounts of nonhazardous wastes in transportable incinerators to very stringent criteria pollutant control. Offsets may also be required in areas that are in nonattainment for $N0_2$, such as The South Coast AQMD (SCAQMD) in California, or nonattainment for ozone, such as the New York metropolitan area.

Most of the relevant regulations specify an emissions rate or level that may not be exceeded or that will trigger corrective or punitive measures. For example, the PSD NO_x triggers are 91 tonnes/yr (100 tons/yr) for new sources and 36 tonnes/yr (40 tons/yr) for retrofits. By contrast, the nuisance rules are catch-all rules that seek to prevent injury or annoyance to any considerable number of persons or to the public. Although these nuisance rules do not appear aggressive or overbearing, the regulatory power of the public cannot be overstated. Public opposition can be more effective in stalling an incineration project than Federal, State, or local regulation. Indeed, public opposition can stall a project already approved and permitted by the authorities. The process for granting permits to install and operate usually have provisions for public input, especially for waste treatment projects. Permitting can easily become the most expensive and time-consuming part of deploying any incineration treatment project, including a Pyretron application.

3.5 Monitoring Requirements

Pyretron system applications will most likely be required to monitor CO and NO_x emissions. The NO_x requirements will likely come from State and local AQMD regulatory pressure for NO, control and, in some areas, for ozone reduction. Continuous monitoring will likely be required. The CO requirement will stem from the Federal and State incinerator regulations calling for continuous monitoring. State and local AQMD emissions limits also exist for CO, but Pyretron system applications are likely to be well below these.

Incineration treatment systems will also be required to continuously monitor such variables as combustion temperature, waste feedrate, and an indicator of combustion gas velocity. Further, if the waste contains sulfur, scrubbing and SO_2 monitoring may be required by the air regulations. Other sampling, analysis, equipment monitoring, and inspections may be required as outlined in 40 CFR 264 Section 347. Finally, incineration systems will be required to observe blowdown discharge and ash residue disposal requirements during operation and at closure. Unless the operator can demonstrate according to 40 CFR 261.3(d) that the residue removed from the incinerator is not a hazardous waste, he will have to manage it in accordance with the applicable requirements of 40 CFR Sections 262 through 266. Even for nonhazardous discharge, local water quality board regulations as well as Federal and State regulations will likely be enforced either as “applicable” or as “relevant and appropriate.” Further guidance on these regulations are available in CERCLA Section 121(d)(2)(A) and (B) as well as 40 CFR Section 35.

Again, it is worth noting that these regulations apply to all incineration systems in general, as well as to Pyretron system applications. The Pyretron is only at a disadvantage with respect to NO, emissions. With further development of the system, this disadvantage could be eliminated.

3.6 Applicable Wastes

The Pyretron system can be used to treat any waste amenable to treatment by conventional incineration. This includes wastes where hazardous constituents are organic and wastes with sufficient organic content that significant volume reduction is possible with incineration, as well as aqueous wastes. Nitrogen containing wastes should not be treated because of the potential to exacerbate NO_x emissions. As explained above, the main advantage of the Pyretron, throughput increases, are obtained for low heating value wastes and not for high heating value wastes. This is because the throughput increases possible with the Pyretron are based on a reduction in combustion gas volume. Combustion gas volume reductions allow throughput increases predominantly with low heating value wastes. Higher heating value waste throughput is limited by the heat release capacity of the incinerator and the capacity for water injection to control kiln temperature.

Wastes with relatively low heating value are most appropriate for treatment with the Pyretron even if they contain contaminants that might be expected to contribute to transient emissions. Despite the results of studies at AEERL which suggest that elevated flame temperatures may increase transient formation in some wastes, the formation of transient emissions did not result in significant operational problems as compared with the heat release limitations of the kiln.

At the start of the demonstration it was believed that the onset of transient process upsets would limit waste throughput rate. The results of the demonstration indicate that this was not the case for the waste studied here. The waste used during the demonstration had a relatively high heating value of 24.1 MJ/kg (10,400 BTU/lb). It was believed that this waste would readily cause transient emissions to occur when fed at high rates to the kiln and so would be an appropriate waste to use to test the ability of the Pyretron to increase throughput rates of such wastes. Not only did this waste not form transient emissions readily, the throughput increases achieved with the Pyretron seemed mostly the result of the 136 Whr of water injected into the kiln to provide added heat absorption capacity. While transient emissions may limit incineration capacity when some wastes are treated (see Appendix D), this is certainly not a universally occurring phenomenon and the dominant factor limiting the throughput of high heating value wastes is the heat release capacity of the kiln.

Materials handling requirements for a Pyretron system application are the same as would apply to a conventional incinerator application. These would include waste pretreatment, probably waste containerization, and treatment residuals handling and disposal.

3.7 Personnel Issues

3.7.1 Operator Training

Training required for an operator of the Pyretron system in a waste incineration application includes that required by all hazardous waste incinerator operators plus training specific to the Pyretron system.

The training required of all hazardous waste incinerator operators is detailed in 40 CFR 264 subpart B, Section 264.16 subpart C on preparedness and prevention as well as subpart D on contingency plans and emergency procedures that also present issues central to personnel training.

Additional operator training specific to the Pyretron system may be required because of the generally more sophisticated process control system and the use of liquid oxygen.

3.7.2 Health and Safety

The health and safety issues involved in using the Pyretron system for waste incineration are generally the same as those that apply to all hazardous waste incineration processes as detailed in 40 CFR 264 subparts B through G.

3.7.3 Emergency Response

The emergency response training for using the Pyretron system is the same general training required for operating a treatment, storage and disposal (TSD) unit engaging in incineration as detailed in 40 CFR 264 subpart D. Training must address such fire-related issues as extinguisher operation, hoses, sprinklers, hydrants, smoke detectors and alarm systems, self-contained breathing apparatus use, hazardous material spill control and decontamination equipment use, evacuation, emergency response planning, and coordination with outside emergency personnel (e.g., tire/ambulance).

3.8 Summary

The Pyretron Thermal Destruction System is an innovative combustion system for application to waste incinerators.

The Pyretron system can be used to treat any waste amenable to treatment via conventional incineration. However, it is best for the treatment of wastes with low heating value. For this reason, it may be quite useful in the treatment of Superfund site wastes.

The available performance data for the Pyretron system were obtained during the SITE demonstration test program performed at EPA's Combustion Research Facility from November 1987 through January 1988 and from a study at the EPA's AEERL laboratory in Research Triangle Park, North Carolina. That study is summarized in Appendix D.

While the Pyretron with oxygen enhancement was able to successfully decontaminate wastes at twice the throughput rate possible with air-only operation, the high levels of NO_x observed during the site demonstration may limit its applicability in situations in which stringent NO_x control is required.

Section 4
Economic Analysis

This section discusses the estimated marginal cost and savings of adding a Pyretron system to a conventional incineration unit during a Superfund site remediation. A primary goal of this analysis is to provide the reader with an independent cost analysis which will help evaluate the validity of the vendor's claim that the addition of the Pyretron system can provide the conventional incinerator operator with significant cost savings.

It is important to remember that the Pyretron Thermal Destruction System is not a stand-alone technology. Employing the Pyretron is a matter of retrofitting it to, or installing it on, a conventional incinerator. Thus, this analysis will employ an incremental cost approach that is different than other economic evaluations conducted for the SITE program. Taking this approach means that this economic analysis will focus on estimating the incremental costs and benefits which are likely to arise from adding a Pyretron burner to an existing incinerator. This analysis will not attempt to estimate the total clean-up costs possible under incineration, with or without the retrofit. Ultimately, the end user must factor the incremental costs and benefits of using this system into a total cost estimate for incineration.

4.1 Methodology

This analysis will employ the same methodology as used by the vendor. The reader will find the vendor's assumptions and methodology detailed in Appendix B. It is a fundamentally sound approach, and by using the same methodology, it will be possible for the reader to make cross comparisons between the vendor and Agency estimates. The key feature of this analysis is that where it is appropriate, alternate assumptions have been substituted for those offered by the vendor. These alternative assumptions, and the rational behind their use, will be offered in a later section. Every attempt has been made to present the analysis in sufficient detail so that the reader is provided the ability to reconstruct any portion of the economic analysis using their own assumptions or cost information. Lastly, the level of detail achieved by this analysis corresponds to an order-of-magnitude estimate as defined by the American Association of Cost Engineers. An order-of-magnitude estimate has an accuracy of +50 percent to -30 percent.

As noted in Appendix B, ACI claims that the cost savings are possible with the use of the Pyretron technology in treating wastes with certain characteristics. They further state that these savings outweigh both the additional capital cost of the Pyretron system and the cost of supplemental oxygen, such that a user realizes a net economic benefit. Our analysis suggests that this claim is valid only under those conditions where the addition of the Pyretron system leads to a significant increase in waste throughput. The analysis presented in this section shows that the degree to which the benefits outweigh additional costs is dependent on a small group of underlying cost and operating assumptions.

The engineering analysis of this system suggests that the average waste throughput can be nearly doubled when the unit is burning lower BTU wastes. (In fact, the reader should note that during the SITE demonstration, throughput was doubled even though a higher heating value waste was used). Increased throughput means less time on site, which translates into reduced operating expenses. If operating cost are particularly high, the result will be a significant process cost savings. This is primarily a result of better utilization of the capital (as represented by the incinerator) coupled with decreases in total labor costs.

4.2 Assumptions

Whether or not net savings are realized in a given treatment project depends on the specific cost values applicable to the above cost elements. In an economic evaluation, the relative magnitude of cost savings and additional costs will be greatly influenced by assumptions made regarding:

- The cost of capital
- The cost of the incinerator
- The labor rates
- The number of incinerator operators needed
- The cost of incinerator's auxiliary fuel

- The cost of oxygen
- The cost of water
- The total amount of waste to be treated

The cost categories listed below are common to all SITE program economic analyses. Their impact on the incremental cost or savings of the Pyretron system are summarized below. Certain cost elements were not analyzed for incremental cost or savings as the addition of the Pyretron system had no impact on these items under the given scenario. Those areas not analyzed include:

- Site Preparation
- Permitting/regulatory requirements
- Startup Costs
- Effluent Treatment and Disposal
- Residuals and Waste Shipping, Handling, & Transport
- Site Demobilization

Facility Modifications/Repair/Replacement: While no incremental cost or benefit was calculated for this analysis, the reader should be alert to the possible need for making significant modification to their incinerator to accommodate the Pyretron.

Those areas where this scenario suggested potential incremental costs or benefits exist include the following:

- Capital Equipment: An incremental cost due to the purchase of the Pyretron system. An incremental benefit due to greater capital utilization.
- Labor: An incremental benefit due to greater utilization.
- Supplies and Consumables: An incremental benefit due to lower fuel consumption. An incremental cost due to oxygen consumption.
- Utilities: An incremental cost due to increased water requirements.

The remediation scenario which will serve as a base case for our analysis, as well as the other assumptions used in the economic analysis are detailed in Table 2.

For the purpose of this analysis it was assumed that the capital cost of he Pyretron system, labor rates, and the cost of water are unchanged from those used in the vendor claims section (Appendix B). The analysis presented in this section focuses on alternative assumptions regarding the cost of capital, the capital cost of the incinerator, labor requirements, overall utilization rates, auxiliary fuel cost, and oxygen costs.

One of the trade-offs brought about by this process is the substitution of oxygen for supplemental fuel. The reader should note that pure oxygen is a relatively expensive raw material, and as such, it's use in industrial applications is generally limited. Costs of obtaining bulk quantities of oxygen can vary greatly, and will be dependent on both total quantities needed and availability of local sources. The least expensive oxygen source would be under a long-term contract and obtained via pipeline direct from an oxygen generation plant. The most expensive source of oxygen would likely be from suppliers who make small bulk deliveries intermittently. For the purpose of this analysis, the oxygen and propane cost used reflect an average of selected 1988 government contract prices as negotiated by the General Services Administration (GSA) for federal facilities utilizing similar quantities of these raw materials(4).

While this analysis assumes that the labor rates used by the vendor are reasonable, the quantity of labor needed to operate the incinerator was increased over that suggested by the vendor. The rational was based on past experiences with other conventional incineration operations. First, we assume a 24 hr/day, 3 shift operation. It was assumed that one senior engineer would supervise the overall operation. Each shift would employ one operator and one assistant. An additional 5 material handlers would work the day and swing shift, and 3 material handlers would work the night shift. It was further assumed that per diem costs would be incurred for the senior engineer, the three operators, and the three assistants. No per diem costs were established for the material handlers as it was assumed they would be hired locally. A per diem cost of $75.00/day/person for these 7 individuals was factored into the calculation. Table 1 shows how the daily labor cost was computed, highlighting labor rates, hours worked, and per diem. For the purpose of this analysis, a total daily labor cost of $3,825.80 was used.

4.3 Cost Evaluation

The remediation scenario and assumptions discussed in Appendix B and 4.1 were used to determine the following incremental costs or benefits of the Pyretron system.

4.3.1 Capital Costs and Benefits

We first assume that the retrofit will occur on a conventional incinerator that has an hourly throughput, when operating at 100 percent utilization, of 0.635 tonne/hr (0.7 ton/hr). Given that an incinerator retrofitted with the Pyretron burner has the potential to double throughput, the new capacity, again at 100 percent utilization, is 1.27

Table 1. Daily Labor Rate Calculation

Shift	Job title[a] ($)	No.	Hr./day	Wage rate[b] ($)	Daily wage ($)	Per diem ($)	Daily total ($
Day	SE	1	8	46.00	368.00	75	443.00
	O	1	8	30.00	240.00	75	315.00
	A	1	8	17.00	136.00	75	211.00
	MH	5	40	1500	600.00	0	600.00
Swing[c]	0	1	6	33 00	264.00	75	339.00
	A	1	8	18.70	149.60	75	224.00
	MH	5	40	16.50	660.00	0	660.00
Night[c]	0	1	8	36 00	288.00	75	363.00
	A	1	8	20.40	163.20	75	238.00
	MH	3	24	18.00	432.00	0	432.00
							3,825.80

a SE = Senior Engineer; 0 = Operator; A = Asst. operator; MH = Material handler.
b The wage rate is a loaded rate which assumes a multiplier of 2 on worker salary to account for fringe benefits, administration costs, and profit. Engineering wage from (5).
c The swing and night shifts reflect a 10 percent and 20 percent differential, respectively.

Table 2. Cost Evaluation Assumptions

Parameter	Conventional system	Pyreton system
Common factors:		
Incinerator size, (nominal total heat input)	12 MW (40 MMBtu/hr)	
Quantity of waste treated	4,472 tonnes (4,930 tons)	
Heat content of waste	24.16 MJ/kg	
Incinerator capital cost	$2,500,000	
Auxiliary fuel and cost	Propane at $3.86/GJ ($4.07/MMBtu)	
Oxygen cost	$0.132/sm^3 ($3.75/MSCF)	
Water costs	$0.0008/L ($0.003/gal)	
Equipment lifetime	15 years	
Interest	9 percent/yr	
Firing/feedrate (total heat input)	12 MW (40 MMBtu)/hr)	15 MW (51 MMBtu)/hr)
Propane heat input	7.41 MW (25.3 MMBtu)/hr)	6.36 MW (21.7 MMBtu)/hr)
Oxygen feedrate	--	1,760 sm^3/hr
Water feedrate	--	1,820 L/hr (480 gal/hr)
Pyretron capital cost	--	$100,000
Royalty fee	--	$8.26/tonne ($7.50/ton)
Waste feedrate (100 percent utilization)	0.635 tonne/hr (0.7 ton/hr)	1.27 tonne/hr (1.4 ton/hr)
Utilization rate	80 percent	75 percent
Waste feedrate (adjusted utilization)	0.508 tonne/hr (0.56 ton/hr)	0.9525 tonne/hr (1.05 ton/hr)
Job duration at given utilization rate	36724-hr days	196 days

tonne/hr (1.4 ton/hr). If 100 percent utilization is assumed to mean 24 hr/day, 365 days/yr, the potential yearly throughput for the conventional incinerator is 5,563 tonnes/yr (6,132 tons/yr), and with the Pyretron retrofit in place, this throughput could double to 11,126 tonnes/yr (12,264 tons/yr). However, since 100 percent utilization is highly unlikely in either case, the utilization rate has been set at 80 percent for the conventional incinerator, and 75 percent in the case where the Pyretron system has been adopted.

The reasons for the assumed difference in utilization between the Pyretron and a conventional burner are as follows. First, experience with the Pyretron during the SITE demonstration indicated that it was not as reliable as a conventional burner. While the additional downtime experienced during the demonstration may have simply been the result of operational problems inherent in the first use of a new technology, ACI personnel were onsite throughout the demonstration to presumably solve these problems and prevent significant downtime. During routine use of the Pyretron ACI personnel will probably not be onsite as much. It remains to be seen how their absence will affect the downtime experienced with the Pyretron.

Second, while the use of oxygen may solve operational problems in situations where there is excessive particulate carryover due to excessive gas volumes, it will not increase operational reliability in situations in which that was not a problem in the first place. If the design of the incinerator minimizes particulate carryover, or if the waste is oily and batch fed in containers, particulate carryover may not be a problem. The reliability of the incinerator with an air burner may be high in such cases, and the added complexity of the Pyretron may reduce it.

Thus, for future calculations the conventional incinerator's adjusted maximum yearly throughput is assumed to be 4,451 tonnes/yr (4,906 tons/yr). With the Pyretron unit attached, the adjusted maximum yearly throughput is assumed to be 8,344 tonnes/yr (9,198 tons/yr).

The $100,000 fee charged by ACI as a capital cost of the Pyretron system results in a annualized cost of $l2,406/year. This is calculated using a simple capital-recovery factor formula where the assumed interest rate is 9 percent and equipment life is 15 years. Using the adjusted maximum yearly throughput for an incinerator retrofitted with the Pyretron system, the result is an incremental capital cost of $1.49/tonne ($1.35/ton) when viewed over the life of the system operating at it's potential.

Assuming a capital cost of $2,500,000 for an conventional incinerator, the capital-recovery formula would indicate an apportionment of capital costs at $310,150/yr (using the same 9 percent interest rate and 15 year equipment life). Thus, the yearly capital-recovery factor distributed over the adjusted maximum yearly throughput treated by the conventional system is $69.70/tonne ($63.22/ton) For the Pyretron system, these costs are reduced to $37.17/tonne ($33.72/ton) Adding the incremental cost of the Pyretron unit to the calculated capital-recovery estimate for the incinerator results in the total Pyretron estimate, $38.66/tonne (35.07/ton). Thus, incremental benefit arising from improved capital utilization is the difference between the conventional and Pyretron based units, or $31.04/tonne ($28.15/ton).

4.3.2 Operating Costs and Benefits

The increase in throughput achieved when using the Pyretron system will provide the incinerator operator in this scenario with the ability to reduce the time he needs to be on site. Specifically, the scenario assumed that a total of 4,472 tonnes (4,930 tons) of contaminated soil need to be treated. The conventional incinerator would have to be on the job site for 367 24-hour days to process the waste (assum ing an 80 percent availability factor). The Pyretron system, treating the same amount of waste, would only need to be on site for 196 24-hour days (assuming an 75 percent availability factor). Based on the daily labor cost of $3,825.80 the total project labor cost using conventional incineration would be $1,404,068.60. By installing the Pyretron system, and reducing the number of operating days, the total project labor cost would be reduced to $749,856.80. The difference between the two results in a savings of $654,211.80. Thus, there is an incremental benefit due to labor savings of $146.29/tonne ($132.70/ton).

For a conventional incinerator of the assumed size, the supplemental fuel (propane) consumption rate was calculated to be 7.41 MW (25.29 MMBtu/hr). Using average GSA propane price of $3.86/GJ ($4.07 MMBtu) described above, the result is a fuel cost of $102.93/hr of operation. With an adjusted hourly throughput (at 80 percent utilization) of .508 tonne/hr (0.56 tons/hr), this converts to fuel costs of $202.62/tonne ($183.80/ton). The corresponding supplemental fuel (propane) consumption rate for the Pyretron system is 6.36 MW (21.71 MMBtu/hr). Again, using the average GSA propane price, the result is a fuel cost of $88.35/hr of operation. With an adjusted hourly throughput (at 75 percent utilization) for the Pyretron incinerator of 0.9525 tonne/hr (1.05 tons/hr) this converts to a fuel costs of $92.76/tonne ($84.15/ton). This results in an incremental benefit due to fuel savings of $109.86/tonne ($99.65/ton).

The oxygen supply rate in this scenario was calculated to be 1,760 sm^3/hr (62 MSCF/hr). Using the average GSA oxygen cost of $0.132/$sm^3$

($3.75/MSCF), the oxygen cost for the Pyretron incinerator is $232.50/hr of operation. At the adjusted throughput rate of .9525 tonne/hr (1.05 tons/hr) this converts to an oxygen cost of $244.09/tonne ($221.43/ton). Since the conventional incinerator uses no oxygen, this cost is considered an incremental cost. Water injection costs for the Pyretron system remain at $1.00/tonne ($0.90/ton).

The last operating cost to consider is the royalty fee charged by ACI. It is a flat rate of $8.26/tonne ($7.50/ton) of waste treated. This is an incremental cost for the Pyretron system.

4.3.3 Benefit Summary

Table 3 summarizes the incremental treatment savings and <costs> projected for the Pyretron system under the assumptions presented above. Shown for comparison is the evaluation based on vendor-supplied cost data which is discussed in Appendix B.

The data in Table 3 show that for the waste treatment application evaluated, use of the Pyretron system offers significant cost savings over conventional incineration in the case where waste throughput can be increased.

While not explicitly considered within this analysis, the reader needs to be alert to a number of factors which will alter the results of this analysis. These include the following:

Only a complete engineering analysis for a particular incinerator configuration will indicate to degree to which increases in throughput are possible. This is a critical assumption as all subsequent cost calculations are dependent on this fact.

Incinerator operators who consider retrofitting their equipment to accommodate the Pyretron should take care in considering the cost of equipment modifications.

This analysis suggests that the degree to which one will enjoy incremental cost savings is heavily influenced by the labor requirement and wage rates.

Different assumptions regarding the cost of capital (interest rates), the capital cost of the incinerator, and the methods for apportioning capital cost (i.e., capital recovery factor) will all impact the potential for incremental savings.

The trade-off between oxygen and the supplemental fuel source is a direct result of their underlying unit cost. Low oxygen costs coupled with high fuel costs will result in the most dramatic savings. High oxygen costs coupled with low fuel cost may result in further incremental costs, offsetting savings in other areas.

Table 3. Summary of Incremental Savings (<Costs>) for the Pyretron System

	Cost Assumption Scenario			
	$/tonne		$/ton	
Increase cost element	Agency[a]	Vendor[b]	Agency[a]	Vendor[b]
Capital costs				
Initial ACI fee	-1.49	-1.5	-1.35	-1.40
Increase in capital utilization	31.04	54.03	28.15	49.12
Operating costs				
Labor	146.29	97.28	132.70	88.44
Supplies				
Propane	109.86	90.86	99.65	82.60
Oxygen	-244.09	- 182.71	-221.42	-166.10
Water	-1 .00	-0.99	-0.90	-0.90
Royalty	-8.30	-8.30	-7.50	-7.50
Total	**32.31**	**48.66**	**29.31**	**44.24**
Total incremental project savings[a]	**$144,400**	**$218,000**		

a **Treating 4,472 tonnes (4,930 tons) of waste**
b **See Appendix B.**

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Appendix A
Process Description

This section provides an overview of the Pyretron Thermal Destruction System. A brief description of the technology is provided in Section A.l; Section A.2 describes the innovative features of the technology and compares the Pyretron system to conventional burners.

A. 1 Treatment Process

The Pyretron Thermal Destruction System is an innovative burner system designed to be used in conjunction with a conventional transportable or fixed incinerator. The system provided for the SITE demonstration consisted of two burners, one installed in the primary combustion chamber (kiln) and one installed in the afterburner; valve trains for supplying these burners with controllable flows of auxiliary fuel, oxygen, and air; a computerized process control system; an oxygen supply system; and a kiln water injection system. A schematic of the system is shown in Figure A-l. The Pyretron burners use a proprietary parallel combustion approach based upon the independent introduction of either pure oxygen, air, or oxygen-enriched air.

The Pyretron burners use the staged introduction of oxygen to produce a hot luminous flame which efficiently transfers heat to the solid waste which is fed separately to the kiln. Oxygen, propane, and oxygen-enriched air enter the burner in three separate streams each concentric to one another. A stream of pure oxygen is fed through the center of the burner and is used to burn propane in a substoichiometric manner. This produces a hot and luminous flame. Combustion is completed by mixing these hot combustion products with the stream of oxygen-enriched air introduced around the outside of the flame envelope.

In a typical Pyretron system Superfund site waste treatment application, many of the equipment systems required are the same as those required by a conventional incinerator treatment process. These are:

- Waste pretreatment and containerization (i.e drumming) equipment
- Waste and residuals analysis facilities
- Containerized waste ram feeder
- Primary incineration chamber and afterburner chamber
- Auxiliary fuel supply system
- Air pollution control system (APCS)
- Residuals (incinerator ash and APCS residuals) treatment and disposal equipment

Equipment systems unique to a Pyretron system application would include:

- Special Pyretron system auxiliary fuel burners
- Special burner auxiliary fuel, air, and oxygen flow control system
- Proprietary combustion process control system
- Oxygen supply system
- Kiln water injection system for high heat content wastes

In a typical Pyretron system application, waste contained in drums will be batch charged to the rotary kiln of a rotary kiln incineration system at a specified charge interval. Organic contaminants in the waste will be volatilized and destroyed via combustion in the vapor phase. Most of the inorganic kaste fraction will traverse the kiln and be discharged as kiln ash. Combustion gas will exit the kiln and flow to an afterburner. The afterburner exists to ensure that essentially complete destruction of organic contaminants occurs. Combustion gas from the afterburner is quenched, then directed to an Air Pollution Control System (APCS). The APCS removes particulate and any acid gases such as HCl resulting from various waste constituents. The APCS residual stream will either be scrubber blowdown from wet scrubber systems or flyash combined with any acid gas dry sorbent from dry APCSs These residuals will not be measurably different from a Pyretron system application than from conventional incineration.

A.2 Innovative Features

The Pyretron system represents an innovative combustion approach for application to an

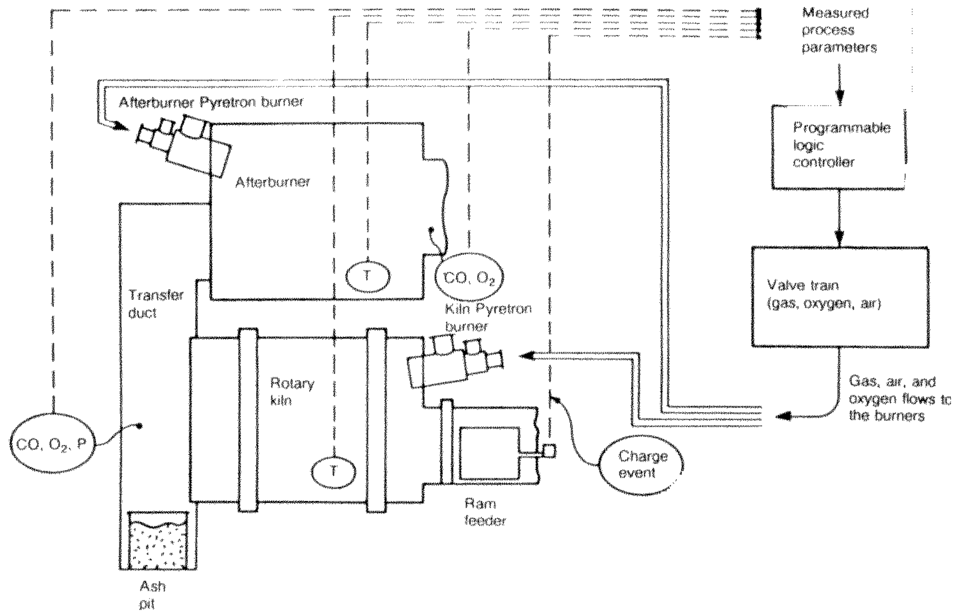

Figure A-l. Pyretron Thermal Destruction System process diagram.

incinerator. One feature unique to the Pyretron system is its dynamic use of pure oxygen to supply a portion of the combustion oxygen needed to destroy organic waste contaminants. "Dynamic use" means that the amount of pure oxygen supplied can be changed in a preset manner based upon the operator's knowledge of the combustion behavior of the waste feed. In this system, oxygen can be used to augment or replace a portion of the combustion air feed to an incinerator's burners.

Although EPA was not provided with documentation on the oxygen flow control system supplied for the SITE demonstration because ACI considers it proprietary, the system worked as follows during the demonstration tests (1). The flowrate of oxygen into the kiln through the Pyretron changed when either of the following four events occurred.

1. Excessive pressure occurred in the kiln chamber and was measured at the kiln exit.
2. Excessive CO was produced in the kiln and was measured at the kiln exit by a CO monitor.
3. Low levels of oxygen occurred in the kiln and were measured at the kiln exit by an oxygen monitor.
4. A certain amount of time had elapsed (approximately 30 seconds) since the activation of the ram feeder to batch charge waste into the kiln.

In response to the first event, the flowrate of air to the burner was reduced to a preset level (or series of levels if needed). The flowrate of oxygen was correspondingly increased in order to keep the overall level of oxygen in the kiln at a constant level.

If either of the remaining three events occurred, the oxygen flowrate was increased in a (preset) stepwise manner. This stepwise increase occurred approximately 30 seconds after activation of the ram feeder even if no fluctuations in CO or oxygen level were detected. There were many feed cycles during the demonstration in which no such fluctuations occurred. At the end of a feed cycle or when the other triggering conditions no longer existed, the oxygen and air levels would return to their "prevent" levels in a similar stepwise manner.

The use of oxygen to enrich the combustion air stream can also be considered an innovative feature of the Pyretron. It provides one additional process parameter which can be varied to maintain optimum operating conditions within the incinerator. The Pyretron is capable of replacing up to 50 percent of the combustion air stream with oxygen.

A.3 CRF Design Considerations

The Pyretron provided by American Combustion was customized for use at the CRF. The burner penetrations in the CRFs Rotary Kiln system were too small, in ACI's opinion, to accommodate a staged burner design typical of what would be used for NO_x suppression. As a result, the burner demonstrated under the SITE program may have produced higher NO_x emissions than would be the case had the burner penetrations been larger.

While it may be true that a different Pyretron would have produced less NO_x, there is no basis for concluding that a different Pyretron would have achieved the large throughput increases that the Pyretron demonstrated at the CRF did.

Appendix B
Vendor Claims

This section summarizes the claims made by the developer about the technology under consideration. EPA does not necessarily agree with all of the statements made in this section. EPA's point of view was discussed in Sections 3 and 4 of this report.

American Combustion, Inc. (ACI) the developer of the Pyretron Thermal Destruction System, states that the Pyretron system offers three advantages over conventional rotary kiln incineration in treating high organic content wastes. These are:

- The Pyretron system will be capable of reducing the magnitude of transient high levels of CO, unburned hydrocarbon, and soot ("puffs") that can occur with repeated batch charging of a high heat content waste to a rotary kiln.
- The Pyretron system will allow increased waste feedrate to the kiln while still achieving the hazardous waste incinerator performance standards for POHC destruction and removal efficiency (DRE) and particulate emissions.
- The Pyretron system is more economical than conventional incineration.

Discussion of the first two claims is presented in Section B.l. Section B.2 presents an economic analysis supporting the third claim based on vendor supplied cost data.

B.1 Incinerator Operational Benefits

The first ACI claim regarding the Pyretron Thermal Destruction System is that the Pyretron system will be capable of reducing the magnitude of transient puffs that can occur with repeated batch charging of a high heat content waste to a rotary kiln. The basis for this claim follows. Rotary kiln incinerators are unique in that they are designed to allow a portion of their. waste load to be introduced or charged to the system in a batch rather than continuous mode. For organic, heating value-containing wastes, a portion of the heat input to the system is correspondingly introduced in a batch mode. Typically, containerized waste, in cardboard, plastic, or punctured steel drums is charged to the kiln at established intervals. Upon entry to the kiln, the waste containers are heated until they rupture or burn. This then exposes the waste contents to the hot kiln environment. Volatile organic material then rapidly vaporizes and reacts with available oxygen in the combustion gas. However, if the volatilization of organic material is more rapid than combustion oxygen can be supplied to the kiln, incomplete combustion can result. This can lead to a "puff' of incompletely destroyed organic material exiting the kiln. In most instances, this puff will be destroyed in the system's afterburner. In fact, afterburners are included in rotary kiln incinerator systems for this very reason. However, if the puff is of sufficient magnitude, insufficient excess oxygen and/or residence time may exist in the afterburners to allow its complete destruction.

In conventional incineration systems, the only way to ensure that sufficient oxygen exists in the kiln for complete waste oxidation is to increase the air flowrate to the kiln. This can either be accomplished by steadily firing the kiln burner at higher excess air than needed to burn the burner fuel, or by dynamically increasing the air flowrate in anticipation of a puff. In either instance, an increased air flowrate adds both increased oxygen for waste combustion and increased nitrogen. The increased diluent nitrogen flow is detrimental to complete waste destruction for two reasons. Its presence in the combustion gas volume decreases kiln combustion gas residence time and, since it must be heated, it decreases combustion gas temperature.

In contrast, the Pyretron system offers the ability to dynamically increase the amount of oxygen in the combustion process in anticipation of a puff while not adding diluent nitrogen. Thus, kiln temperature can be more easily maintained and additional oxygen needed for waste puff destruction can be introduced with less effect on combustion gas volume, hence combustion gas residence time, than possible with air alone. A programmed system response is possible in which oxygen flow to the burner is increased after a suitable lag time after batch charge addition. This extra oxygen, without diluent nitrogen, is available for waste puff oxidation. With this additional kiln condition control flexibility, the magnitude of transient puffs should be reduced as compared to similar operating conditions with conventional incineration.

An additional point which ACI makes is that new EPA regulations of CO levels will require existing incinerators to implement combustion and control equipment which is as sophisticated as the Pyretron system. These regulations will require incineration operators to continuously monitor CO and compute rolling averages as well as shut-off the waste feed while continuing auxiliary fuel input when CO levels are exceeded.

The second ACI claim regarding the Pyretron system is that its use will allow increased waste throughput in a rotary kiln system while maintaining acceptable, in-compliance, incinerator operation. The basis for this claim follows from the basis of the first claim. The maximum feedrate of a high organic content waste in a conventional incinerator is determined by the onset of transient puffs which survive the afterburner. When this occurs, waste constituent destruction is less than complete, and eventually falls below the regulation mandated 99.99 percent hazardous constituent destruction and removal efficiency.

The discussion supporting the first claim noted that, since the additional oxygen to support waste combustion would be supplied without diluent nitrogen in the Pyretron system, incineration residence times would be greater for a given waste and auxiliary fuel feedrate; therefore, incineration destruction efficiency would be greater. Thus, a feedrate that produced unacceptable transient puffs under conventional incineration would not with the Pyretron system. Correspondingly, the onset of unacceptable transient puff generation under Pyretron operation would occur at a higher waste feedrate. Thus, acceptable operation at higher waste feedrates (or throughputs) should be possible with the Pyretron system.

B.2 Process Economic Evaluation

The third ACI claim noted in the introduction to Appendix B was that the Pyretron system is more economical than conventional incineration. The basis for this claim follows from the bases for the first two claims. Since the Pyretron system uses oxygen for a portion of the waste oxidant (instead of air), a given set of incineration temperatures can be maintained with less auxiliary fuel feed than possible with conventional incineration. Less diluent nitrogen is fed, thereby obviating the need to heat this diluent nitrogen to combustion temperature. Thus, auxiliary fuel use per unit of waste treated is less for the Pyretron system than for conventional incineration.

In addition, if higher waste feedrates can be employed in a given combustor with the Pyretron system, then the treatment time required per unit of waste is decreased. This affords further operating cost savings, as well as capital recovery costs per unit of waste treated.

ACI claims that these cost savings more than offset Pyretron system capital costs and oxygen purchase costs. The claim is supported by the following economic analysis. The analysis is based on cost and pricing data supplied by ACI along with certain assumptions made about the type and quantity of waste treated by the system.

B.2.1 Method and Assumptions

The operating characteristics of a conventional RKS and the same kiln retrofitted with the Pyretron system were determined during the SITE demonstration tests discussed in Appendix C. The SITE demonstration was performed on a 880 kW (3 million Btu/hr) pilot-scale rotary kiln incinerator. The waste used was a mixture of contaminated soil from the Stringfellow Superfund site (approximately 40 percent, by weight) and the listed waste K087, decanter tank tar sludge from coking operations (approximately 60 percent, by weight). The mixture had a heat content of about 24.16 MJ/kg (10,410 Btu/lb). As detailed in the Technology Evaluation Report (2), operating parameters were varied to determine the optimum throughput, fuel feedrate, and air and oxygen feedrates. These optimum values are summarized in Table B-l. In keeping with EPA policy, the measurement units reported use SI units as the primary citation with English units in parentheses. Unit conversions used in this section are summarized in Table B-2.

Using the optimum operating conditions, the ratio of heat input from waste to heat input from fuel was determined for the two treatment approaches, conventional incineration and the Pyretron system. These ratios were then used to determine waste throughput, fuel, and oxygen consumption for a 12 MW (40 MMBtu/hr) nominal total heat input RKS. This size RKS was selected as being representative of transportable systems now in use.

The Pyretron system employs water injection to maintain the correct kiln temperature when feeding high heating value wastes. The addition of this heat sink also enables the Pyretron system to handle a higher heat content loading rate per nominal kiln capacity. In the demonstration tests, an 880 KW (3 MMBtu/hr)-rated RKS was able to handle 1.1 MW (3.8 MMBtu/hr) of total heat input with the Pyretron system in operation. For the economic analysis then, a nominal 12 MW (40 MMBtu/hr) RKS was assumed capable of handling 15 MW (51 MMBtu/hr) of total waste and auxiliary fuel heat input with the Pyretron system applied.

Table B-1. Optimum Operating Parameters Determined in the Demonstration Test Program[a]

Parameter	Conventtonal system	Pyretron system
Waste feedrate	47.7 kg/hr (105 lb/hr)	95.5 kg/hr (210 lb/hr)
Propane heat input	550 kW (1.9 MMBtu/hr)	480 kW (1.6 MMBtu/hr)
Oxygen feedrate	–	131.4 sm^3/hr (4,640 scf/hr)
Waste heat input	320 kW (1.1 MMBtu/hr)	640 kW (2.2 MMBtu/hr)
Total heat input rate	870 kW (3.0 MMBtu/hr)	1.120 kW (3.8 MMBtu/hr)
Fraction of heat input from fuel	0.63	0.43
Fractton of heat input from waste	0.37	0.57

[a] Demonstration tests performed in 880 kW (3 MMBtu/hr) pilot-scale rotary kiln incinerator.

Table B-2. Unit Conversion (Si-English) Used in this Analysis

1 kg = 2.20 lb
1 metric ton (1 tonne) = 1,000 kg = 2.200 lb = 1.10 tons
1 sm^3 = 35.31 sci[a]
1 MJ/kg = 430.8 Btu/lb
1 kW = 3,412 Btu/hr
1 J = 1,055 Btu

Denotes standard conditions of 1 atm and 15.6°C (60°F).

B.2.1.1 Treatment Cost Assumptions

As discussed above, ACI claims that the Pyretron system can be used to enhance the performance of a conventional RKS. In this context, the Pyretron system is affected by the same factors as any other incineration technology would be, such as type of waste, cost of auxiliary fuel, labor rates, etc. Because this analysis treats only incremental costs, these common factors have been ignored.

Use of the Pyretron system results in both benefits and additional costs compared to a conventional system. Briefly, the Pyretron system incurs the cost of purchasing oxygen, water for kiln temperature control, and extra capital costs (as discussed below). Benefits of the Pyretron system are lower auxiliary fuel costs and higher throughput for certain waste types. This allows lower labor costs per ton of waste treated and better utilization of capital cost for such wastes.

In essence, ACI's claim is that the benefits outweigh the costs for appropriate waste types. This economic analysis was performed to determine the validity of this claim. The primary data required to perform the analysis were:

- The incremental capital cost of the Pyretron system
- The cost of incinerator operator labor
- The cost of incinerator auxiliary fuel
- The cost of oxygen
- The cost of water

To perform the analysis, a hypothetical remediation scenario was developed. For the conventional system, a job duration of 1 year was selected. Based on the estimated throughput capacity of a conventional RKS burning the same waste as that used in the demonstration test, the total mass of waste treated was determined. It should be noted that the heat content of the waste used in the demonstration test was higher than what may typically be found at a Super-fund site, although Superfund site wastes with such heat content are likely to exist. Many Superfund site wastes are oily sludges with significant heat content. However, the most common Superfund site waste is a contaminated soil with low total organic content. The high waste heat content had the effect of reducing the throughput capacities of both systems to a level below that possible with a very low heat content waste.

The total mass of waste treated was calculated assuming 24-hours per day, 7 days per week, and 52 weeks per year operation, and an availability factor of 80 percent for a conventional incinerator system. That is, it was assumed that the conventional RKS would operate, on average, 80 percent of the time or 6,900 hours a year. The demonstration test program determined that 37 percent of the total heat input to the conventional RKS came from the waste. For a nominal 12 MW (40 MMBtu/hr) incinerator burning a waste with a heat content of 24.16 MG/kg (10,410 Btu/lb) a throughput of 640 kg/hr (0.7 tons/hr) is implied. Multiplying the number of operating hours by the throughput yields the total mass of waste treated in the scenario, 4,480 tonnes (4,930 tons).

The demonstration test program determined that the Pyretron system allowed an increase in heat input to the incinerator of 28 percent. Thus, an incinerator rated at a nominal 12 MW (40 MMBtu/hr) could operate at 15 MW (51 MMBtu/hr). In addition, the demonstration showed that the Pyretron system allowed 57 percent of the heat input to come from the waste. The net effect of these two factors is the doubling of throughput for the Pyretron system over conventional incineration. A total of 4401 hours (183.4 24-hr days) are required to treat the 4,480 tonnes (4,930 tons) of waste assumed in this scenario. The treatment project durations and throughput capacities of the two systems directly affect labor costs and capital utilization. Along with fuel, oxygen, and water costs, these factors form the basis for determining the incremental cost or benefit of the system.

The assumptions made in assigning treatment costs for conventional incineration and a Pyretron application are discussed in the following paragraphs. Many of the costs associated with the application of a conventional RKS are identical to those costs that would be incurred by a Pyretron RKS. In those cases, no incremental costs (or benefits) would be expected. Cost categories where this is true have been so indicated.

Design and Application Engineering Costs

Design and application engineering costs include site preparation, permitting and regulatory, and capital equipment costs. Assumptions for these are discussed in the following paragraphs.

The site preparation cost category includes site design/layout for development, surveys/site investigations, legal searches, access rights and roads, preparation for support facilities, decontamination trailers, utility connections, foundations, auxiliary buildings, and all other expenses that would be incurred in preparing the site for the installation and operation of the technology. All of these costs would be common to both conventional incineration and the Pyretron system. In addition, the Pyretron system would include all costs incurred by the application of a conventional incinerator. Thus, the Pyretron system does not incur incremental cost nor offer any incremental benefit.

The permitting/regulatory cost category includes all the costs incurred in satisfying the applicable regulatory requirements, such as developing the Safety, Health and Emergency Response Plan (SHERP). Although such plans must accommodate the use of oxygen, it is not expected that the addition of the Pyretron system to an RKS will measurably increase or decrease these costs. Thus, there is no incremental cost or benefit.

For the purpose of this economic analysis, capital equipment costs include all one-time costs associated with applying the technology to a remediation site. These include procurement and relocation costs for the RKS, waste and material handling equipment and support facilities.

ACI has indicated that it does not intend to sell the Pyretron system on the basis of ACI's cost to produce the equipment but on a basis of the improved performance of the incineration operation (3). For an incineration system of the size used in this analysis, ACI estimates that the Pyretron TDS would be provided for an initial fee of approximately $100,000, depending upon the required modifications to the computerized process controller, and a royalty of $7.50 per ton of waste fed through the system. The fee would cover assistance from ACI in performing the trial burn, training of operators on an ongoing basis, maintenance of the equipment, and assistance in optimizing the system for a given waste stream. For this analysis, the $100,000 fee has been defined to be the incremental capital cost, and the royalty fee has been allocated to incremental operating costs. The higher throughput possible with the Pyretron system also allows the capital invested in the base incinerator system to be used more efficiently than in a conventional application. This improvement in capital utilization is discussed in detail later in this section. All other differences in capital equipment costs (as defined above) were considered negligible.

Operating Costs

Operating costs include startup, operating labor, operating supplies, and utilities costs. Assumptions for these are discussed in the following paragraphs.

Due to the increased complexity of the Pyretron system it was assumed that startup activities will consume an extra week of operating time over the 1 week estimated for a conventional system. However, this cost was assumed to be included in the fee and royalty charges.

It is expected that neither the number of operating personnel nor the average labor rate would be different for the Pyretron system as compared with a conventional RKS. However, a cost benefit will accrue by using the Pyretron system due to the higher throughput. This will allow the same mass of waste to be treated in a shorter period of time; thus, fewer labor hours will be required per weight of waste treated. The labor categories and rates used to determine the daily crew costs are summarized in Table B-3.

The demonstration test used propane as the auxiliary fuel for both the conventional and Pyretron systems. Many fuels (and wastes) may be used as auxiliary fuels at a remediation site. However, for the purposes of this analysis it was assumed that propane would be used. In addition, the heat content of Superfund site wastes can vary over a broad range. In this analysis, it was assumed that waste with the same heat

Table B-3. Crew Costs – Daily Loaded Rate[a] (24-Hour Operation)

1 Supervising Engineer, 8 hr/day @ $46/hr
1 Operator (each shift), 24 hrs/day @ $30/hr)
1 Assistant (each shift), 24 hrs/day @ $17/hr
2 Material handlers (each shift), 24 hrs/day @ $15/hr

Shift	Hours	Labor Category	Rate	Cost($)
Day	8	SE	46.00	368
	8	O	30.00	240
	8	A	17.00	136
	16	MH	15.00	240
Swing[b]	8	O	33.00	264
	8	A	18.7	150
	16	MH	16.50	264
Graveyard[c]	8	O	36.00	288
	8	A	20.00	163
	16	MH	18.00	288
Total				$2401/ 24-hr day

[a] Loaded rate assumes a multiplier of two on worker salary to account for fringe benefits, overhead, administrative costs, and profit.
[b] 10 percent shift differential for swing
[c] 10 percent shift differential for graveyard.

content as the waste used in the demonstration test would be treated.

For a conventional RKS of the assumed size, a fuel (propane) consumption rate of 7.41 MW (25.3 MMBtu/hr) was calculated. The waste throughput was estimated to be 640 kg/hr (0.7 tons/hr). For the Pyretron system the corresponding fuel (propane) consumption rate was 6.36 MW (21.7 MMBtu/hr). The throughput of the Pyretron system was estimated to be 1,270 kg/hr (1.4 tons/hr). Propane was assumed to cost $5.70/GJ ($6.00/MMBtu) per ACI's recommendation (3). One of the main elements of the Pyretron system is the dynamic use of oxygen in the combustion process. The oxygen supply rate was calculated to be 1,760 sm^3/hr (62 MSCF/hr), and oxygen was assumed to cost $0.088/$sm^3$ ($2.50/MSCF) per ACI's recommendation (3). The Pyretron system also requires water injection to maintain the appropriate kiln temperature. The water consumption rate for this system was estimated to be 1,820 Whr (480 gallons/hr). Water costs were assumed to be $0.0008/L ($0.003/gal). Makeup requirements of the pollution control system were assumed to be unchanged. All other supplies, were assumed to be common to both systems; therefore, there was no impact on incremental costs or benefits.

VENDOR EDITORIAL COMMENT. AT THE VENDOR'S REQUEST, THE FOLLOWING COMMENTSAREREPEATEDVERBATIMFROM AMEMORANDUMFROMMARKZWECKER TO EPA DATED MARCH 24, 1989

The analysis included in the report shows untypically high fuel costs when test result are scaled to a 40 MMBtu per hour incinerator. Therefore, it is obvious that the methods used for scaling need to take into account additional factors. Specifically this analysis must take into account the untypical length/diameter ratio of the CRF kiln which results in rates of heat loss that are unusually high when compared to heat losses for a commercial incineration system.

The length/diameter ratio of the CRF kiln is between 2 and 2.5, while this ratio for a typical system varies from 5 to 7. Based on these ratios and typical heat inputs for commercial incinerators, the outside surface area of the CRF kiln per unit heat release is in the range of 2.3 to 2.8 times higher than for a commercial incineration system. Since the heat loss through the walls is directly proportional to the wall area, the relative heat losses for the CRF kiln should be expected to much higher than for a typical commercial incineration system.

Heat losses from commercial incinerators typically amount to about 5 percent of the total heat input (EPA's Handbook for Hazardous Waste Incineration). Based on the increased relative surface area of the CRF system, heat losses for this system are approximately 13 percent. This number is representative and has been verified by heat balances performed by ACI at the initial stages of testing.

Therefore, the heat losses for the CRF kiln are approximately 160 percent higher than a typical system. These large heat losses and the high excess air levels required for incineration will significantly impact fuel consumption and can lead to very high estimates of fuel costs when scaling up test data if not accounted for in the calculations. ACI's analysis shows that by applying these factors correctly when scaling to a commercial size unit much more realistic estimates of fuel costs can be obtained.

End of Vendor Editorial Comments

Utility costs such as telephone, drinking water, and sanitary facilities are not expected to differ between the two systems. Electricity costs for the air supply fan may change, but for the purposes of this analysis this incremental cost was assumed to be negligible.

Effluent Treatment and Disposal

The effluent streams for both systems consist of flue gas, air pollution control system discharge (e.g., scrubber blowdown), and kiln ash. The discharge of flue gas entails no cost, and the total quantity of air pollution control system discharge and kiln ash is expected to remain the same. Therefore, the incremental costs for this category between the two systems was assumed to be negligible.

In addition, there are costs associated with the preparation of the residual waste for shipping, interim storage, waste disposal, and loading and transportation costs. The characteristics and total quantity of residual waste produced by the two systems is assumed to be the same, only the rate at which it is produced is different. Because the costs detailed above are not time dependent, no incremental cost/benefit is expected.

Analytical Costs

It was assumed that the Pyretron equipped RKS would require the same analytical monitoring equipment and techniques as a conventional RKS. Any additional monitoring equipment costs were assumed to be included in the incremental capital costs. Also, it was assumed that no increase or decrease in the frequency of analysis would be involved. That is, analysis costs are incurred on a per-ton-treated basis as opposed to a time basis. Expenses incurred under analysis costs include site demonstration monitoring, environmental monitoring, Quality Assurance/Quality Control, and reporting requirements. Since none of these cost items is likely to be different between the two systems, no incremental cost or benefit is expected.

Facility Modifications/Repair/Replacement

This cost category includes design adjustments, facility expansion, and equipment parts and replacement. These costs were assumed to be covered by ACI's initial fee and royalty payment. Modifications, repairs, or replacement of parts on the incinerator that are not covered by the vendor are common to both systems and were not included in the determination of the incremental costs.

Site Demobilization

Unlike startup costs, it was assumed that the Pyretron system would incur the same demobilization costs as a conventional RKS. Thus, no incremental cost or benefit is expected for shutdown, site and equipment decontamination, site restoration, permanent storage, or site security costs.

B.2.1.2 Basis for Determining Incremental Cost of Benefit

To determine the incremental cost or benefit, each cost category was normalized to a dollars-per-ton-of-waste-treated basis. This was accomplished by dividing the individual costs by the total mass of waste treated in the scenario. Incremental capital costs were determined by first converting the capital cost (present value) to an annualized cost using the capital recovery formula:

$$\text{Annual cost} = P * \frac{i(1+i)^n}{(1+i)^n - 1}$$

where

P is the present value of the investment,
i is the interest rate per period and
n is the number of periods

The $100,000 fee which would be paid to ACI for the Pyretron system was converted to an annual cost assuming a 15-year equipment life (this is considered reasonable for a transportable rotary kiln system), no salvage value, and an interest rate of 11 percent per annum. The Pyretron system allows a higher throughput for a given size incinerator. Assuming that the system has the same equipment life, this improves the utilization of base incinerator capital. That is, more tons of waste could be treated for the same capital cost. The improvement in capital utilization due to increased throughput was calculated as an annual cost (actually an annual benefit) by determining the annual capital cost of the 12 MW (40 MMBtu/hr) RKS assumed in the scenario, and dividing this figure by the estimated annual throughput for the conventional system. The capital cost of a system this size was assumed to be $3,500,000. As with the ACI fee, the capital cost was converted to an annual cost assuming an equipment life of 15 years, no salvage value, and an interest rate of 11 percent. This step was then repeated using the estimated annual throughput of the Pyretron system. The difference between these two values ($/ton) represents the incremental cost benefit due to improved capital utilization gained by using the Pyretron system.

B.2.1.3 Cost Assumption Summary

The cost categories and their impact on the incremental cost or benefit of the Pyretron system are summarized below:

- Design and Application Engineering Costs
  - Site preparation costs: no incremental cost or benefit
  - Permitting/regulatory requirements: no incremental cost or benefit.
  - Capital equipment costs: An incremental cost of $100,000 due to ACI's fee. An incremental benefit due to the greater capital utilization caused by higher throughput.

- Operating Costs
  - Startup costs: no incremental cost or benefit.
  - Labor costs: an incremental benefit due to higher throughput.
  - Supplies: An incremental benefit due to lower fuel consumption and an incremental cost due to the cost of purchasing oxygen.
  - Utilities: no incremental cost or benefit
- Effluent Treatment and Disposal: no incremental cost or benefit.
- Residuals and Waste Shipping, Handling and Transport: no incremental cost or benefit.
- Analytical Costs: no incremental cost or benefit.
- Facility Modifications/Repair/Replacement: no incremental cost or benefit.
- Site Demobilization: no incremental cost or benefit.

The remediation scenario, the assumptions discussed above, and the other assumptions used in the economic analysis are detailed in Table **B-4.**

B.2.2 Cost Evaluation

Based on the remediation scenario and assumptions discussed in Section B.2.1, the following incremental costs or benefits generated using the Pyretron system were determined.

B.2.2.1 Capital *Costs and Benefits*

The $100,000 fee charged by ACI to use the system results in a annualized capital cost of $13,906/year. Based on an estimated throughput for the Pyretron system of 8,918 tonnes of demonstration test-type waste per year (9,811 tons/year) this results in an incremental capital cost of $156/tonne ($1.42/ton)

Based on an 80-percent availability factor, the conventional RKS was estimated to have an annual throughput of 4,480 tonnes (4,930 tons). The Pyretron system was estimated to have a throughput of 8,911 tonnes (9,833 tons). Based on a capital cost of $3,500,000, the capital cost per tonne of waste treated for the conventional system was $108.64/tonne ($98.73/ton) The capital cost per tonne of waste treated for the Pyretron system was $54.62/tonne ($49.61/ton). The incremental capital benefit from improved capital utilization is the difference between these two figures, $54.02/tonne ($49.12/ton).

B.2.2.2 *Operating Costs and Benefits*

The increase in throughput made possible using the Pyretron system allows the quantity of waste treated in the scenario to be completed in less time using the same crew size. Specifically, the scenario assumed that the conventional system was on the job site for 365 24-hour days, with 80 percent availability (20 percent downtime). The Pyretron system was assumed to treat the same amount of waste in 183.4 24-hour days (with 80 percent availability).

The following tables illustrate the cost analyses conducted. Table B-4 lists the cost assumptions for the vendor's economic analysis. They are similar to the assumptions made in Section 4 of this report except that the vendor uses a higher capital cost, interest rate and availability factor for the Pyretron.

B.2.3.3 Benefit Summary

The total incremental benefit for the Pyretron system based on the incremental capital and operating costs and benefits is $48.67/tonne ($44.26/ton). The individual incremental costs and benefits are summarized in Table B-5.

As the above analysis indicates, ACI's claim that the Pyretron system is more economic to operate than conventional rotary kiln incineration systems is supported based on data supplied by ACI. In the scenario examined in this analysis, approximately 68 percent of the cost savings can be attributed to reduced operating costs.

A discussion of economics from EPA's perspective based on high, low and average costs, was provided in Sec tion 4.

VENDOR EDITORIAL COMMENT. AT THE REQUEST OF THE VENDOR, THE FOLLOWING COMMENTS ARE REPEATED VERBATIM FROM A MEMORANDUM FROM MARK ZWECKER DATED MARCH 24, 1989.

One of the most important subjects overlooked within the EPA's analysis of the PYRETRON system in the Technology Application Analysis, Section 6.5.2, is risk assessment. This is a subject that regulators, acting in the public's interest, must fully explore when evaluating new technologies or applications of equipment for handling toxic materials. ACI, while not attempting to imply any corporate ability to conduct risk analyses, offers the following summary of how the Pyretron system will impact a typical hazardous waste incinerator.

Risk Assessment

One of the most significant issues relating to hazardous waste incineration is the potential risk to the environment and population due to the release of toxic contaminants from the activity. Release of contaminants may occur due to stack discharge of pollutants or due to a variety of other potential fugitive emissions.

Table B-4. Cost Evaluation Assumptions

Parameter	Conventional system	Pyretron system
Incinerator size (nominal total heat input)	12 MW (40 MMBtu/hr)	12 MW (40 MMBtu/hr)
Firing/feedrate (total heat input)	12 MW (40 MMBtu/hr)	15 MW (51 MMBtu/hr)
Propane heat input	7.41 MW (25.3 MMBtu/hr)	6.36 MW (21.7 MMBtu/hr)
Oxygen feedrate	--	1760 sm^3/hr (62 MSCF/hr)
Water feedrate	--	1820 L/hr (480 gal/hr)
Waste feedrate	640 kg/hr (0.7 ton/hr)	1270 kg/hr (1.4 ton/hr)
Base capital cost	$3,500,000	$3,500.000
Incremental capital cost		$100.000
Royalty fee		$8.26/tonne ($7.50/ton)
Availability factor	80 percent	80 percent
Job duration	365 24-hr days	183 24-hr days
Common factors:		
Quantity of waste treated	4480 tonnes (4930 tons)	4480 tonnes (4930 tons)
Heat content of waste	24.16 MJ/kg (10,410 Btu/lb)	24.16 MJ/kg (10,410 Btu/lb)
Auxiliary fuel and cost	Propane at $5.70/GJ ($6.00/MMBtu)	Propane at $5.70/GJ ($6.00/MMBtu)
Oxygen cost	$0.088/$sm^3$ ($2.50/MSCF)	$0.088/$sm^3$ ($2.50/MSCF)
Water cost	$0.0008/L ($0.003/gal)	$0.0008/L ($0.003/gal)
Crew	1 operator, 1 assistant, 2 material handlers per shift, and 1 supervising engineer day shift	1 operator, 1 assistant. 2 material handlers per shift, and 1 supervising engineer day shift
Crew cost	$2401/24-hr day	$240 1/24-hr day
Equipment lifetime	15 years	15 years
Interest rate	11 percent/yr	11 percent/yr

Table B-5. Summary of Incremental Savings and (Costs) for the Pyretron System

	$/tonne	$/ton	$/MMBtu[a]
Capital cost and savings;			
Initial ACI fee	(1.50)	(1.40)	(0.07)
Increase in capital utilization	54.03	49.12	2.36
Operating costs and savings:			
Labor	97.28	88.44	4.25
Supplies			
Propane	90.86	82.60	3.97
Oxygen	(182.71)	(166.10)	(7.98)
Water	(0.99)	(0.90)	(0.04)
Net supply savings	(92.84)	(84.40)	(4.05)
Other			
Royally	(8.30)	(7.50)	(0.36)
Total savings	$48.67/tonne	$44.26/ton	$2.13/MMBtu

[a] $/KW are negligible so only $/Btu are shown.

For this reason risk assessments are being more consistently required by regulators before incineration activities can be permitted. Risk assessments are also being used more aggressively in conjunction with the Right-to-Know regulations and programs. A risk assessment includes four elements. These elements are hazard identification, dose-response assessment, exposure assessment, and risk characterization. Any incineration activity should have a risk assessment performed to determine the potential worst case results of incinerating hazardous components.

The PYRETRON TDS testing at the CRF has shown some significant improvements for the incineration of hazardous wastes. These improvements will also translate into positive benefits in risk assessment. When performing a risk assessment,the PYRETRON system may directly reduce the risk associated with hazardous waste incineration activities in three ways;

1 The project duration time is reduced for a given tonnage of waste material.

2. The PYRETRON system Transient Upset Control System, specifically designed to respond to prefailure conditions, reduce occurrence of failure modes that result in harmful releases to the atmosphere.

3. The PYRETRON system should more consistently maintain a higher destruction efficiency (DE) due to a reduction of the volume of inerts entering the process.

These elements of improved control and increased productivity combine to lower both the potential emissions from the system and the human exposure time. The net result is that even though a conventional system may be able to attain acceptable risk levels the PYRETRON system will reduce the risks.

End of Vendor Editorial Comment

Appendix C
SITE Demonstration Results

This section summarizes the results of the SITE demonstration of the Pyretron system as they pertain to the evaluation of the developers claims. A more detailed report on the demonstration is found in the companion Technology Evaluation Report which has been published previously (2).

The demonstration tests of the Pyretron Thermal Destruction System were performed on a prototype system retrofitted to the pilot-scale rotary kiln incineration system at EPA's Combustion Research Facility (CRF) in Jefferson, Arkansas. The demonstration program began in November 1987 and was completed in January 1988. This program was conducted using a mixture of 60 percent by weight decanter tank tar sludge from coking operations, RCRA listed waste K087, and 40 percent soil excavated from the Stringfellow Superfund site near Riverside, California. Table C-l summarizes the POHC concentrations resulting from this waste mixture.

Table C-l POHC Concentration Estimate[a]

Naphthalene	62 ± 5.4[b]
Acenaphthylene	15 ± 2.7
Fluorene	7.6 ± 1.8
Phenanthrene	28 ± 3.4
Anthracene	8.3 ± 1.8
Fluoranthene	14 ± 2.2

[a](2)
[b]95 percent confidence Interval.

The scope of the demonstration test program is described in Section C.1. Section C.2 discusses test program results. Test program conclusions are given in Section C.3.

C.l Demonstration Test Program

As noted above, the demonstration tests were performed using a prototype Pyretron system retrofitted to the rotary kiln incineration system (RKS) at the CRF. A simplified schematic of this system is given in Figure C-l.

The prototype Pyretron system retrofitted to the CRF RKS was described in Appendix A. The replacement burners were installed in the RKS in the locations noted in Figure C-l as main burner and afterburner. These burners were designed to fit directly into the existing refractory penetrations for the existing RKS burners. The gas (propane, air, and O_2) metering and control assembly was fabricated by ACI, shipped to the CRF, and installed just outside the building housing the incinerator. The trailer-mounted O_2 tank with evaporator was supplied by Big Three Industries. The ACI-supplied process control computer system was installed in the CRF control room, in parallel with the in-place RKS control system.The ACI system controlled the burner flows (propane, air, and O_2). The existing RKS control system controlled waste feed and scrubber system operation.

For these tests, the fiber pack drum ram feeder system was used to feed waste to the kiln. This system feeds 5.7-L (1.5-gal) fiber pack drums in a cyclical batch charge operation.Drums contained between 4.1 and 7.9 kg (9 and 17 lb) of waste depending on the specific test underway.

Six tests were performed to supply data to evaluate the ACI claims. Since the ACI claims state that the Pyretron system offers superior performance when compared to conventional incineration, one set of operating conditions reflecting the limit of the capabilities of conventional incineration in terms of waste batch charge mass and total waste mass feedrate was tested.

The capability limits for conventional incineration were defined via several scoping tests. These tests confirmed that a waste feed schedule of 10.9 kg (24 lb) every 10 min resulted in unacceptable transients in kiln exit flue gas CO levels. These transient CO puffs survived passage through the afterburner and gave unacceptable CO spikes at the stack. A waste feed schedule of 9.5 kg (21 lb) every 12 min resulted in acceptable incinerator operation.This feed schedule was defined to be the capability limit of conventional incineration and was denoted the optimum conventional operating condition. Two

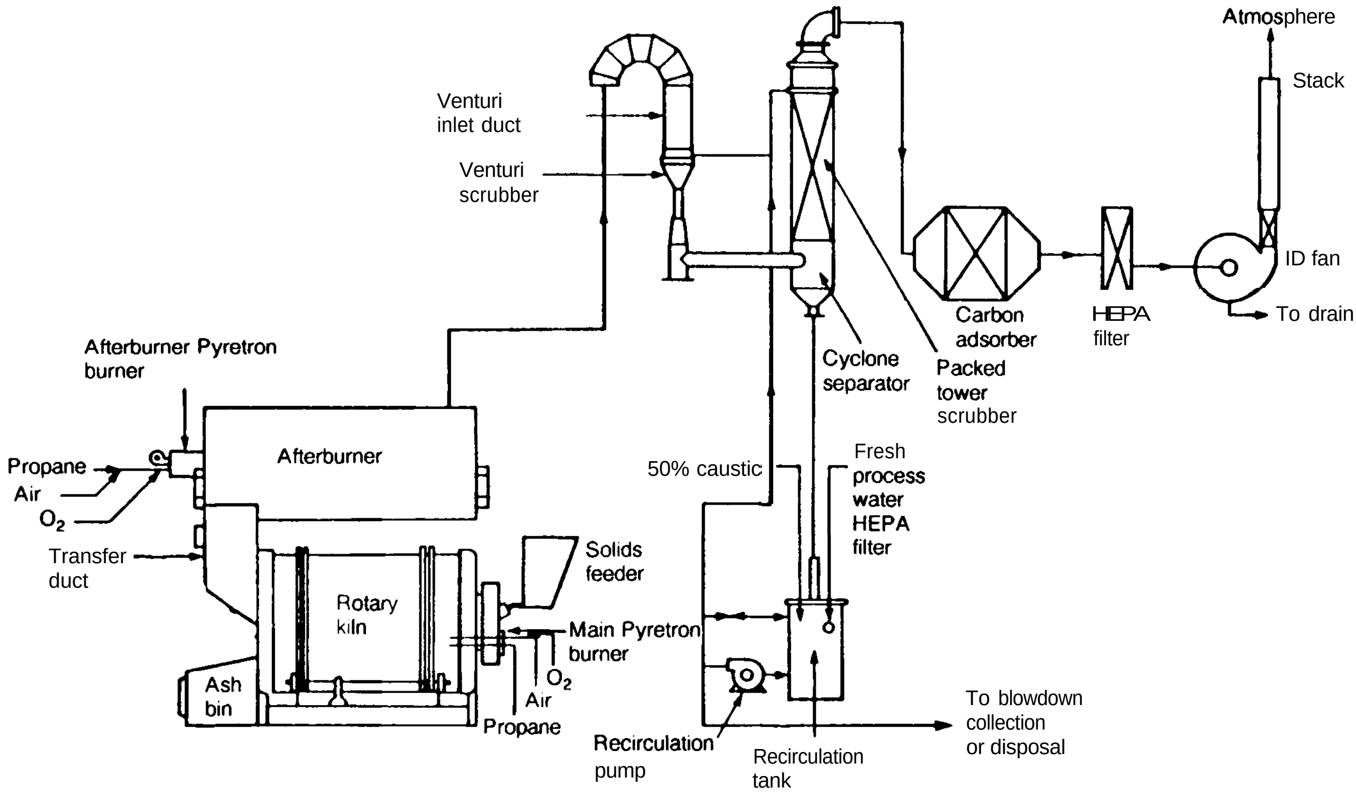

Figure C-1. CRF **rotary kiln system.**

emissions tests (replicates) were performed at this condition.

The other four tests were performed with the Pyretron system in O_2 enhanced operation.The optimum conventional operating condition was repeated with the Pyretron system.Then a waste feed schedule of 15.5 kg (34 lb) every 19.5 min was tested with the Pyretron system to evaluate the ACI claim that the Pyretron system can reduce the magnitude of transient puffs. Finally, a waste feed schedule of 9.5 kg (21 lb) every 6 min was tested with the Pyretron system to evaluate the ACI claim that higher waste feedrates would be possible with the Pyretron system. Two tests (replicates) were performed at this last test condition as well.

Table C-2 summarizes the incinerator operating conditions tested.

C.2 Demonstration Test Results

The results will be described in relation to the claims American Combustion made about the performance of the Pyretron.

As explained in Appendix B, American Combustion contends that the Pyretron can significantly reduce the magnitude of the transient emissions that occur when solid waste is batch fed to a rotary kiln. The demonstration results do not support that contention. After a brief description of the tests that pertain to the evaluation of transient emissions, an explanation of why the results are inconclusive will be given.

Since transients occur over a short period of time, stripcharts from continuous emission monitors were used to detect and record transients as they occurred while the RKS being fed using various charge mass/charge frequency combinations. Figure C-2 plots the variation in incinerator operating parameters for the conventional incineration attempt to feed 10.9 kg (24 lb) of mixed waste every 10 min. The figure shows that, early in the test period, kiln exit temperature varied from about 870 to 980°C (1,600 to 1,800°F) over a charge cycle.Kiln exit O_2 ranged from about 7 to 16 percent over a cycle, and kiln exit CO levels were generally low. However, intermittent CO spikes up to 2,200 ppm occurred. As this test proceeded, kiln temperature increased such that, after about 3 hours of operation,

Table C-2. Average Incinerator Operating Conditions for the Tests Performed

Test	Operation	Waste: Charge weight, kg (lb)	Waste: Charge interval, minutes	Waste: Feedrate kg/hr (lb/hr)	Kiln exit: Temperature °C (°F)	Kiln exit: Flue Gas O_2 percent	Afterburner exit: Temperature °C (°F)	Afterburner exit: Flue Gas percent
--	Conventional, scoping	10.9 (24)	10	65.5 (144)	1027(1880)	9.9	1121 (2050)	6.4
1	Conventional, optimum	9.5 (21)	12	47.7 (105)	954 (1750)	13.3	1121 (2050)	7.7
2	Conventional, optimum replicate	9.5 (21)	12	47.7 (105)	921 (1090)	12.8	1121 (2050)	7.4
3	Pyretron, at conventional optimum	9.5 (21)	12	47.7 (105)	1035(1895)	17.6	1121 (2050)	15.2
4	Pyretron, Increase charge mass	15.5 (34)	19.5	47.7 (105)	963 (1765)	14.5	1121 (2050)	15.0
5	Pyretron, optimum	9.5 (21)	6	95.5 (210)	979 (1795)	13.9	1121 (2050)	14.0
6	Pyretron, optimum replicate	9.5 (21)	6	95.5 (210)	979 (1795)	14.6	1121 (2050)	15.3

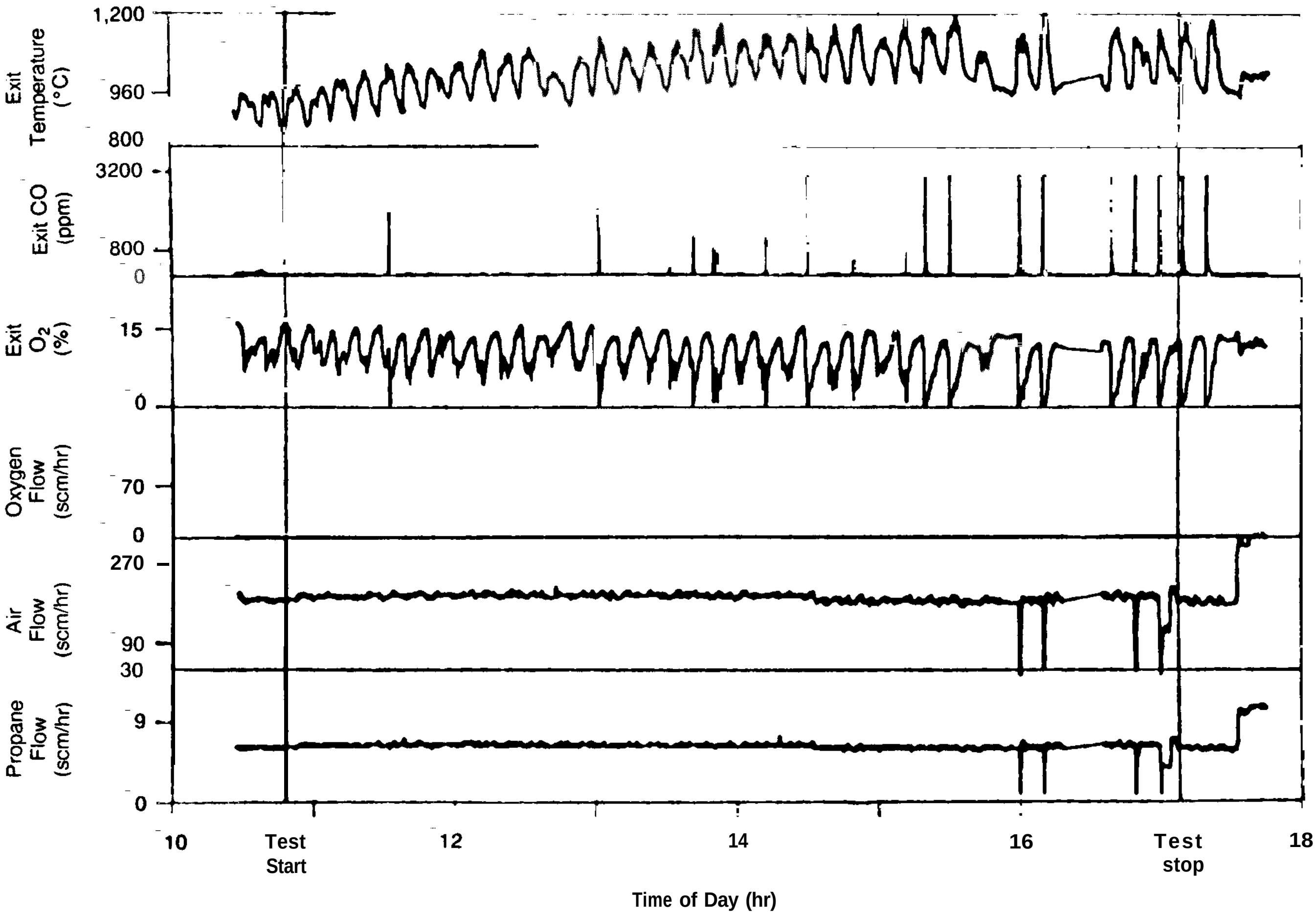

Figure C-2. Kiln data for the conventional incineration scoping test: 65.6 kg/hr (10.9 kg every 10 min).

kiln exit temperature was ranging from 980 to over 1,150°C (1,800 to over 2,100°F) over a charge cycle. Kiln exit flue gas O_2 peaked at about 15 percent just prior to initiating a batch charge, but decreased to 0 as the puff of volatilized waste from a charge filled the kiln. Kiln exit CO levels peaked at about 3,000 ppm under these depleted O_2 conditions. Figure C-3 shows that the CO puffs survived through the afterburner and resulted in CO peaks of above 100 ppm at the stack.

In contrast, operating conditions for conventional operation were much more controlled with a waste feed schedule of 9.5 kg (21 lb) every 12 min, as shown in Figure C-4. At stabilized operation, kiln exit temperature ranged from about 900 to 1,080°C (1,650 to 1,970°F) over a charge cycle. Kiln exit CO peaks were less than about 50 ppm with the one exception, a spike early in the test. These were reduced to less than 10 ppm at the stack after passage through the afterburner.

Figure C-5 shows the variation in operating parameters for the Pyretron system test at an increased charge mass of 15.5 kg fed every 19 min. For this test, average kiln exit temperature was comparable to the conventional incineration optimum condition test at about 960°C (1,765°F), though temperatures as low as 870°C (1,600°F) and as high as 1,065°C (1,950°F) were routinely experienced. Kiln exit flue gas O_2 generally ranged from about 13 to about 19 percent over a charge cycle. However, kiln exit flue gas CO was generally below. This test clearly established that a 60 percent increase in waste batch charge mass (9.5 to 15.5 kg) over the limit of conventional incineration was possible with acceptable emissions transients with the Pyretron system.

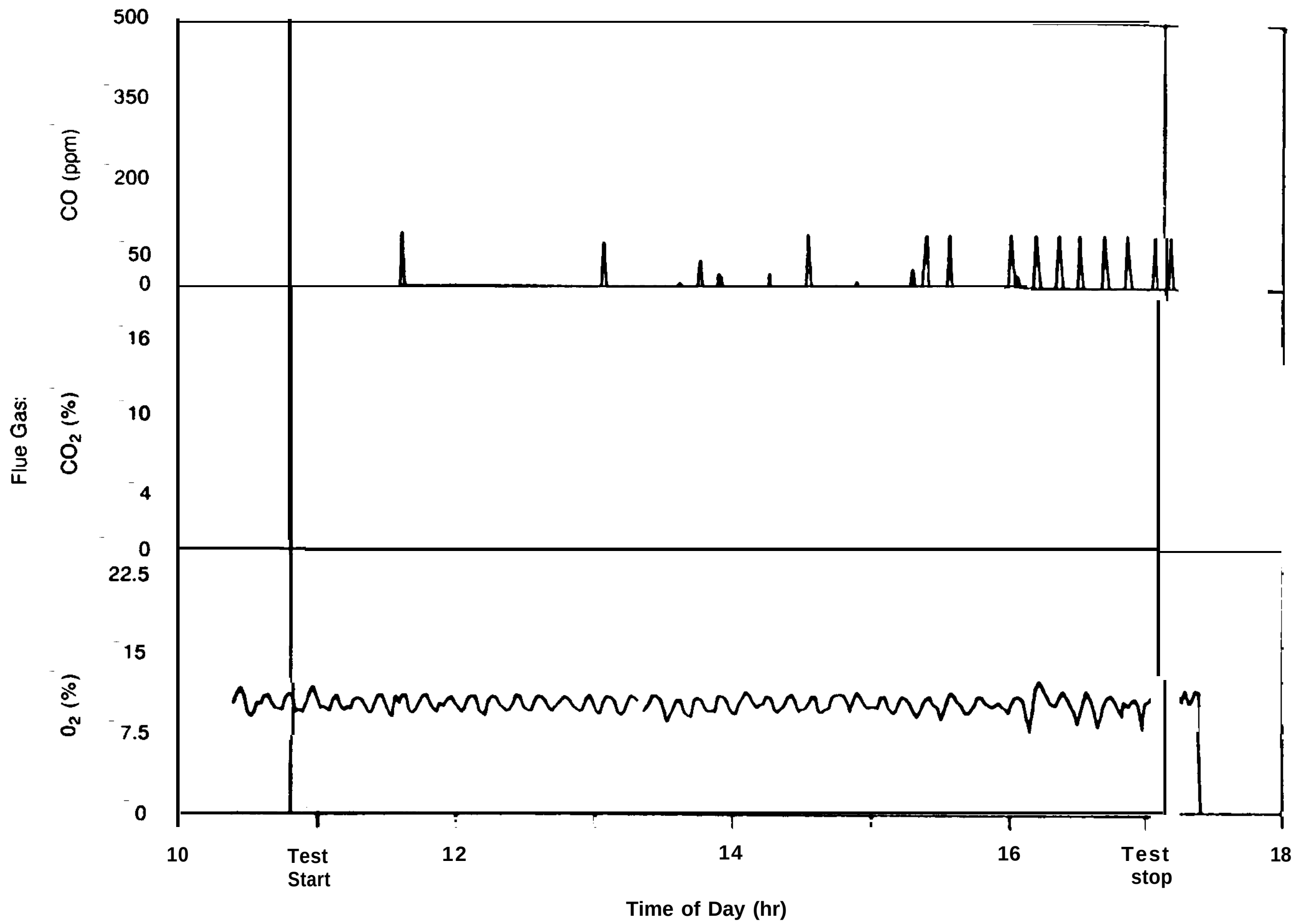

Figure C-3. Stack emission monitor data for the conventional incineration scoping test: 65.6 kg/hr (10k.9 every 10 min)

Figure C-6 shows the variation in operating parameters for the Pyretron system test with a feed schedule of 9.5 kg (21 lb) every 6 min. This represents double the feedrate achievable under conventional operation. As shown in the figure, average kiln exit temperature was about 980°C (1,795°F) with routine variations from about 925°C (1,700°F) to about 1,035°C (1,900°F). Kiln exit flue gas O_2 generally ranged from 11 to 17 percent. Kiln exit flue gas CO peaks of about 100 to 300 ppm occurred when kiln exit fell below about 10 percent. However, for other than these periods, CO levels in the kiln exit flue gas were usually about 30 ppm. This test clearly shows that a waste feedrate double that possible with conventional incineration can be achieved with acceptable emission transients with the Pyretron system. However, to achieve the elevated feedrates demonstrated with the Pyretron system, it was necessary to inject 136 Whr (36 gal/hr) of water into the incinerator to absorb the excess heat released by the waste.

Transient emissions were to be evaluated by comparing the frequency and level of transient CO emissions as measured by continuous emission monitors and recorded on stripcharts. Comparison of the stripchart recordings of CO level for optimum operation under the oxygen enhancement and air only operation, Figures C-4 and C-6 show no obvious visible difference between the frequency and magnitude of transient CO emissions. As mentioned earlier, an average of 16 transients/test were observed during air-only operation. Only 6 transients/test were observed during oxygen-enriched operation. Statistical analysis confirmed that there were no statistically significant differences between the frequency and level of transient emissions that occurred between air-only and oxygen-enhanced operation.(4) Further, these figures indicate that transients do not occur as frequently as one might expect given the high level of organic content of the feedstream.These data

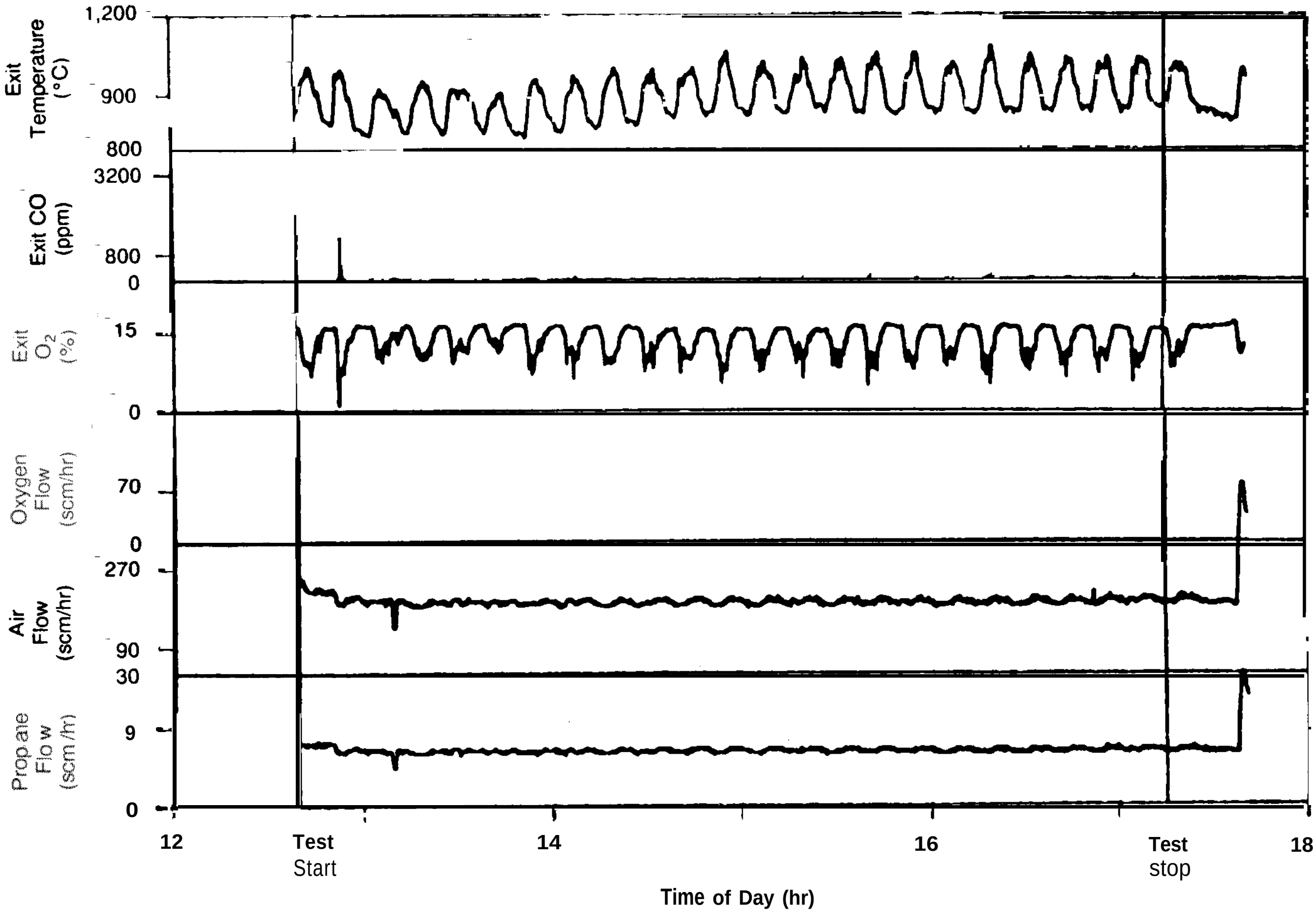

Figure C-4. Kiln data for the optimum conventional incineration test: 47.7 kg/hr (9.5 kg every 12 min)

contrast with Figures C-2 and C-3 which show fairly regular transients towards the end of the test.

There are several possible explanations for the observed difference in transient emissions. Since these were scoping tests, the conditions toward the end were close to the stable operating limits of the incinerator. It is conceivable that transients occur to a significant extent only under suboptimal feeding conditions and not under stable conditions. Since the conditions that caused transients to occur under air-only operation were different than those that caused puffing under oxygen enhanced operation, comparative data were not obtainable.

Another explanation for the irregularity in the onset of transients lies in the nonuniformity of the waste feed. Since the waste feed was a mixture of feed streams that are not necessarily uniform to start with, variations in the level and frequency of transients might be due to variations in the level of organic content in the feed stream over time.

The injection of water into the kiln during oxygen enhanced operation may have altered the frequency and level of transient emissions that would have occurred with use of the Pyretron with oxygen enhancement. This is plausible because the formation of transient emissions is dependent upon kiln temperature.(6,7) Water was injected into the kiln to absorb heat and thus reduce temperatures. The reduction in temperatures may have reduced transient emissions during this mode of operation.

There may also be other reasons why transients did not occur regularly. This result suggests that transient performance is best evaluated in a more controlled situation in which highly uniform specially prepared waste streams can be fed. This was, in fact, done at the U.S. EPA's Air and Energy Engineering Research Laboratory in Research

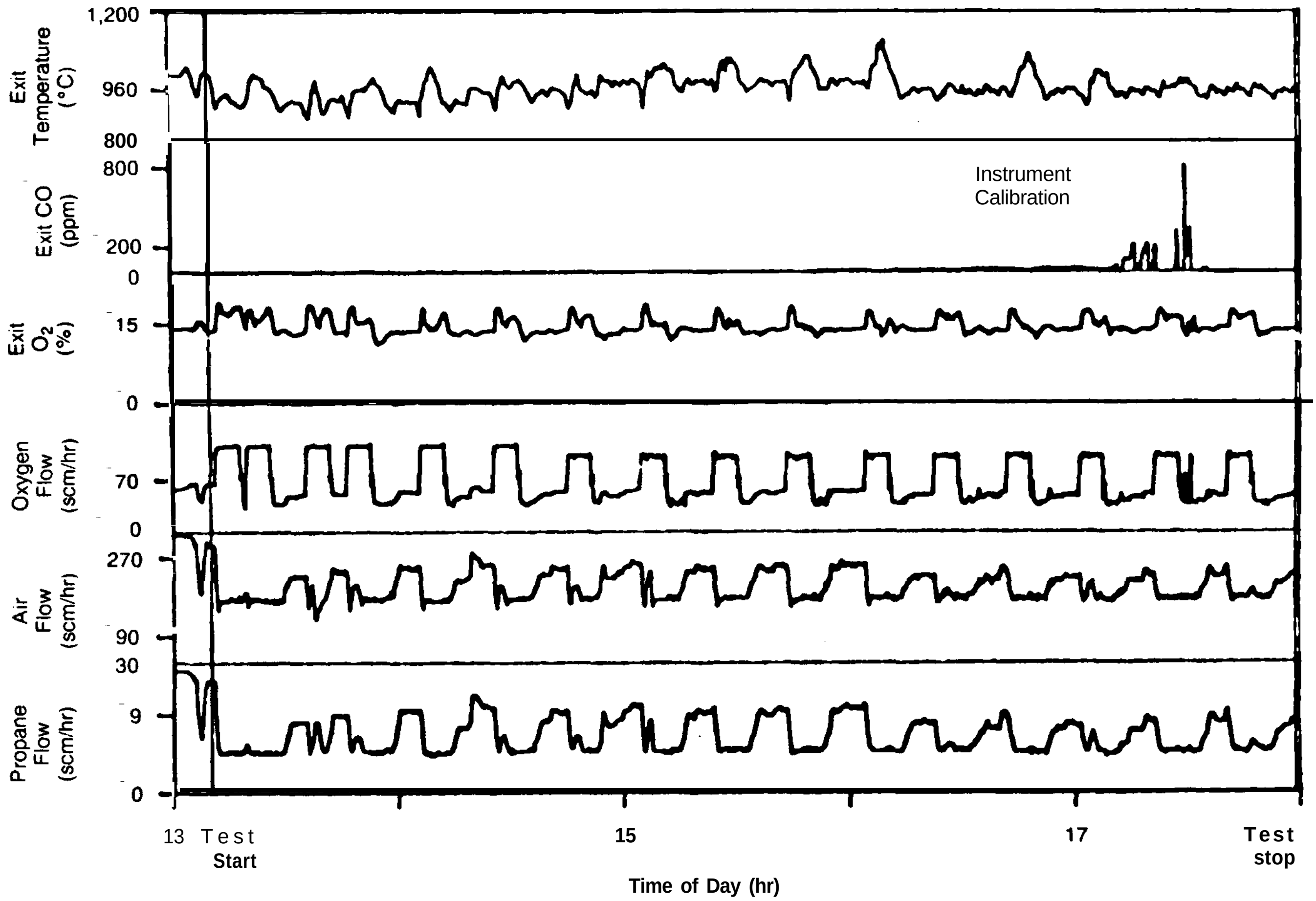

Figure C-5. Kiln data for the Pyretron system test at increased charge mass: 47.7 kg/hr (15.5 kg every 19.5 min)

Triangle Park, North Carolina using a smaller version of the Pyretron. That study will be discussed more fully in Appendix D.

American Combustion also claims that the Pyretron can achieve DREs greater that 99.99 percent at elevated feedrates. This contention is supported by the results of the demonstration. Even at feed rates double those for conventional incineration, incineration with the Pyretron was able to show DREs in excess of the RCRA mandated 99.99 percent. Table C-3 summarizes the DREs achieved for the POHCs in the mixed Stringfellow soil/K087 waste at a location in the flue gas that would correspond to the stack discharge from a typical industrial rotary kiln incinerator. This location is at the packed tower scrubber discharge at the CRF. None of the POHCs designated for these tests were detected in the flue gas at this location. The DREs noted in Table C-3 reflect method detection limits.

As shown in Table C-3, DREs at the scrubber discharge were greater than 99.99 percent for many POHCs. In many instances, detection limits allowed establishing DREs greater than 99.9999 percent for POHCs at higher waste feed concentrations. The good DRE performance in all tests is understandable since all tests were performed at relatively high kiln and afterburner temperatures.

Particulate levels in the scrubber discharge flue gas were in the 20 to 40 mg/dscm at 7 percent O_2 range regardless of test conditions. These levels were below the incinerator performance standard of 180 mg/dscm at 7 percent O_2.

The composite scrubber blowdown liquor and kiln ash samples from each test were analyzed for the test POHCs and other Method 8270 semivolatile organic hazardous constituents and none were detected. Since semivolatile organics were not detected in any residual sample, tiring mode (conventional versus

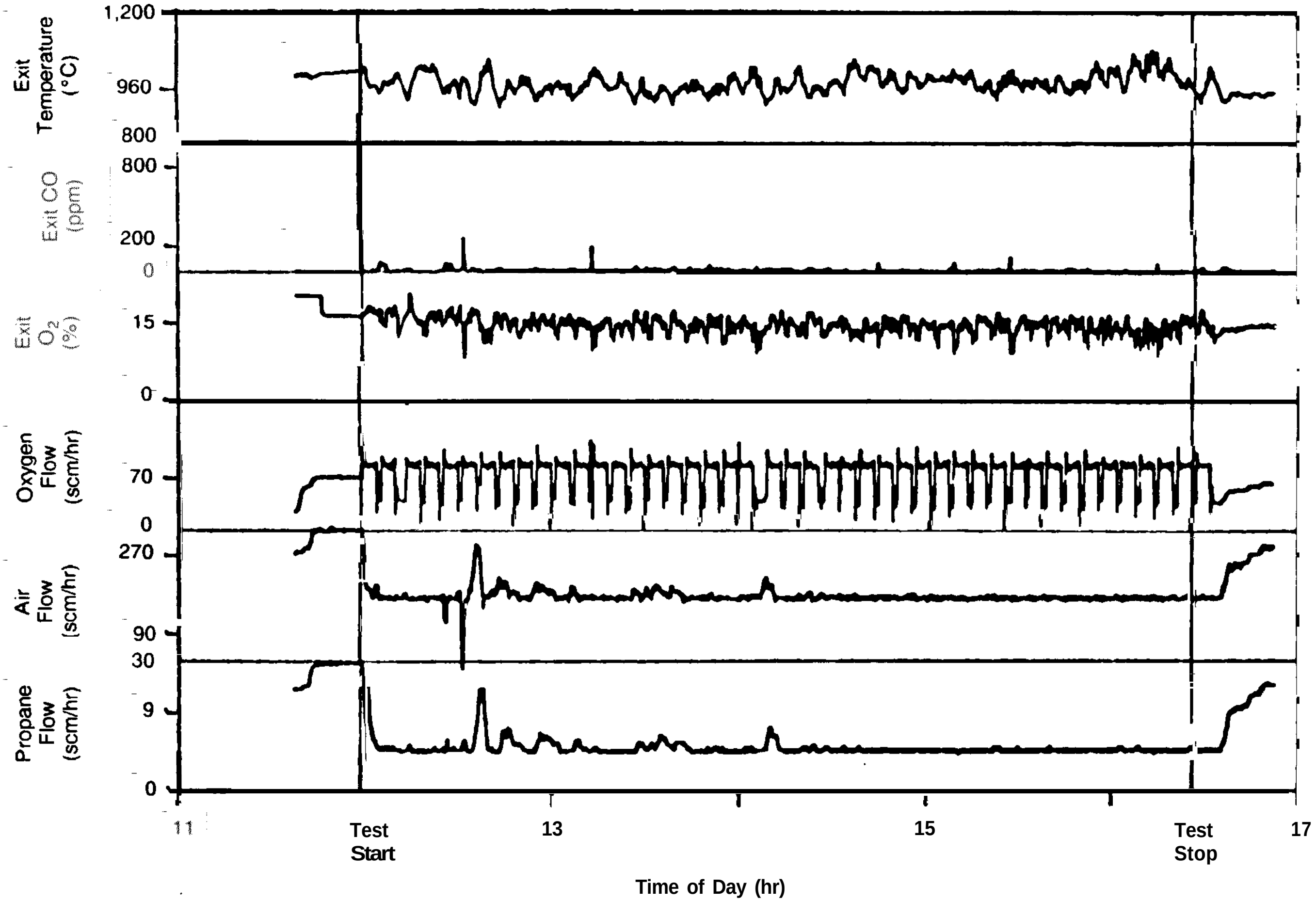

Figure C-6. Kiln data for the optimum Pyretron system test: 95.5 kg/hr (9.5 kg every 6 min).

three conditions of Pyretron O_2 enhanced operation) had no measurable effect on residue composition.

Levels of NO_x were much higher when the incinerator was operated with oxygen enhancement than when operated under air only conditions. Table C-4 summarizes the average NO_x levels that were observed during each run. These levels represent the arithmetic average of all of the non-zero NO_x readings obtained for each test run during the demonstration. These data are presented uncorrected, corrected to 7 percent oxygen and corrected to 7 percent oxygen accounting for the use of pure oxygen. These final corrections were done using correction factors calculated in a manner specified by American Combustion. (8)

C.3 Demonstration Test Conclusions

The objective of the demonstration tests was to provide the data to evaluate the three ACI claims regarding the Pyretron system discussed in Appendix B.

With respect to the first ACI claim, test results are inconclusive. The only available measures of the magnitude of transient puffs in the test program were those recorded by the CO and unburned hydrocarbon emission monitors. Flue gas unburned hydrocarbon levels were uniformly low for all tests. Kiln exit CO peaks were quite frequent for conventional incineration at high waste feedrate (65.5 kg/hr (150 lb/hr)). Kiln exit CO levels were more steady for the lower waste feedrate tests (47.7 kg/hr (105 lb/hr)) regardless of firing mode (conventional versus Pyretron) or batch waste charge mass. However, test-to-test variability in the kiln exit CO data was such that no clear differences between conventional incineration and Pyretron performance were apparent.

Table C-3. Scrubber Discharge POHC DREs

	POHC DRE (percent)					
	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene
Test 1 (12-9-87)						
Train 1	> 99.99934	> 99.9975	> 99.9945	> 99.9985	> 99.9951	> 99.9979
Train 2	> 99.99936	> 99.9976	> 99.9947	> 99.9986	> 99.9953	>99.9980
Test 2 (12-11-87)						
Train 1	> 99.99924	> 99.9967	> 99.9933	> 99.9984	> 99.9945	>99.9974
Train 2	> 99.9964	> 99.984	> 99.968	> 99.9920	> 99.974	> 99.988
Test 3 (12-17-87)	> 99.99896	> 99.9955	> 99.9937	> 99.9979	> 99.9933	>99.9960
Test 4 (1-14-87)	> 99.99978	>99.99910	> 99.9981	> 99.99948	> 99.9983	> 99.9989
Test 5 (1-20-88)						
Train 1	> 99.99989	> 99.99958	> 99.99914	> 99.99976	> 99.99922	> 99.99949
Train 2	> 99.99990	> 99.99961	> 99.99919	> 99.99977	> 99.99927	> 99.99952
Test 6 (1-21-88)						
Train 1	> 99.99991	> 99.99965	> 99.99930	>99.99980	> 99.99935	> 99.99953
Train 2	> 99.99990	> 99.99961	> 99.99923	>99.99978	> 99.99929	>99.99948

Table C-4. NO_x, Levels Observed During the SITE Demonstration

Test	Date	Mode	Uncorrected NO_x Level ± 5%
..	12-08-87	Air	101
1	12-09-78	Air	80.6
2	12-11-87	Air	117
8	1-29-88	Air	67.9
3	12-17-87	O_2	1753
4	1-14-88	O_2	1064
5	1-20-88	O_2	750
6	1-21-88	O_2	725

With respect to the second ACI claim, test results clearly indicate that 99.99 percent POHC DRE was achieved with the Pyretron system with waste feedrate doubled over the limit established under conventional operation provided that water is injected when high heating value waste is treated.

Evaluation of the third ACI claim was discussed in Section 4.

The high levels of NO_x emissions observed indicate a potential problem associated with using this technology at sites where there are stringent limitations on NO_x emissions.This problem could be alleviated through the use of a fully staged burner design. ACI contends that the burner installed at the CRF was not a fully staged design because the burner penetrations on the CRF's rotary kiln were too small.

Appendix D
Case Studies

D.1 Introduction

In this section two instances of the use of oxygen enhanced incineration are described which support results obtained during the SITE demonstration. The first case describes studies conducted by the USEPA's Air and Energy Engineering Research Laboratory (AEERL) in Research Triangle Park, North Carolina. In these studies a small-scale Pyretron was used to study the effect of oxygen enhancement on the reduction of transient emissions from the batch charging of surrogate waste to a rotary kiln simulator. The results of these studies underscore the uncertainty regarding the ability of the Pyretron to reduce transient emissions.

The second case involves the use of an oxygen burner, different from the Pyretron, to burn dioxin contaminated soil at an extended field demonstration of the EPA's Mobile Incineration System at the Denney Farm site near McDowell, Missouri. The results of this case study illustrate how a well planned application of oxygen enhanced incineration can be very effective.

D.2 Pyretron Studies at AEERL

A small version of the Pyretron was installed on a 73 kW (250 kBTU/hr) Rotary Kiln Simulator at the USEPA's AEERL to study the effect that oxygen enrichment might have on the transient emissions that occur when solid waste is batch fed to a rotary kiln.(6) As mentioned earlier, transient emissions occur when organic material that has been batch fed to a rotary kiln suddenly volatilizes and momentarily depletes the oxygen available in the kiln atmosphere. This situation can result in the formation of toxic pyrolysis products.

Three studies of transient formation were conducted by AEERL. The first two were concerned with determining the factors which influence transient formation when solid and liquid wastes are batch fed to the rotary kiln simulator. These studies did not involve the use of oxygen enrichment. The third involved determining the effect that oxygen enrichment has on these emissions.

In the first study, the effects of charge mass, charge area, and kiln temperature on transient formation were determined through a series of experiments in which plastic rods were incinerated in the kiln simulator.(9) Four different types of plastic, Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Polystyrene (PS), Polyvinylchloride (PVC) in rods of different sizes (surface areas) were treated in the kiln simulator at two different temperatures and at 100 percent excess air. Exhaust gas from the kiln simulator was continuously monitored for Total Hydrocarbon (THC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxygen (O_2), and Nitrogen Oxides (NO_x). Peak height and peak area from the THC stripchart recordings were used to measure the intensity and magnitude of the transient emissions formed during these experiments. The results of this study showed that:

1. The four plastics studied showed different transient behavior. While both LDPE and HDPE rapidly formed transient gaseous products, PVC released gaseous products much more slowly during a transient episode. Both PVC and PS require less oxygen for combustion than LDPE or HDPE. This means that PVC and PS deplete the kiln atmosphere of oxygen to a lesser extent than LDPE or HDPE and therefore do not form transient emissions as readily.

2. Regardless of the plastic studied, all formed transients even though the experiments were all conducted with the kiln simulator operating at 100 percent excess air.

3. Increases in temperature increased the rate at which the transient emissions were produced, but seemed to decrease the total amount of material emitted during these transient episodes.

4. Toxic byproducts can be formed during transients, especially when a mixture of chlorinated and nonchlorinated wastes are being batch charged to the incinerator.

In the second study, the effects of charge mass, charge composition, kiln temperature and kiln rotation time were studied in the kiln simulator using a series of liquid chemicals adsorbed onto ground corncobs.(7) The chemicals studied were toluene, methylene chloride, carbon tetrachloride and No.5 Fuel oil. Once again the incinerator was operated at 100 percent excess air and at two temperatures. Exhaust gas monitoring was the same as in the study described above. In addition, however, particulate emissions were also sampled during each transient episode. The conclusions drawn from this study are as follows.

1. Oxidation level in the kiln does not affect the onset of transient emissions. They occurred even though the kiln was operated at 100 percent excess air.

2. Highly toxic byproducts, including dioxins and furans can form during transients, especially when mixtures of chemicals are fed (e.g. carbon tetrachloride and toluene).

3. No single measurement accurately indicates the onset of transient emissions for all feedstreams. Carbon monoxide, THC peak height, THC peak area, and particulate filter weight were all used to detect and measure transients during this study. Different measurements were good measurements for different chemicals. Carbon monoxide was a poor indicator for toluene transients. Since toluene readily forms soot, particulate filter weight was the best indicator. For carbon tetrachloride, CO worked best.

4. Increases in temperature and kiln rotation speed greatly increased the magnitude and intensity of the transient emissions produced.

The third study involved installation of a small version of the Pyretron on the rotary kiln simulator in an effort to determine the effect of oxygen enrichment on transient emissions.(6) Since these emissions seem to be caused by the momentary oxygen depletion of the kiln atmosphere, it was thought that oxygen enrichment might reduce these emissions. The kiln was fired as before and the feedstream for the tests was toluene adsorbed onto corncobs as in part of the previous test. All measurements were identical to those conducted previously. The studies conducted here attempted to determine the effect of stoichiometric ratio, post flame oxygen flow and post flame oxygen partial pressure on the magnitude and intensity of the transient emissions produced. While the effects of post flame oxygen partial pressure and post flame oxygen flow could not be directly determined, some very important results were obtained. These include the following.

1. While some reduction in transient emissions is possible with oxygen enrichment, the higher temperatures that accompany the use of oxygen increase transient emissions far beyond any reduction achieved. *The net effect of the use of oxygen is an increase in transient emissions.*

2. The use of oxygen enriched combustion air leads to very high NO_x levels (as high as 1500 ppm).

3. The production of transient emissions in the kiln probably cannot be prevented and so efforts must be made to assure that these emissions are eliminated in the afterburner.

D.3 Integration of These Results with Those of the SITE Demonstration

The results of the SITE demonstration were inconclusive with respect to the ability of the Pyretron to reduce transient emissions. There are three possible reasons why this is so. First, perhaps the Pyretron did not reduce transient emissions. The studies conducted at AEERL indicated that the elevated temperatures that result from using oxygen enrichment may increase transient emissions.(6)

Second, the waste used may not have been the type that readily forms transient emissions. The organic contaminants in the waste used during the SITE demonstration were polycyclic semivolatile organic compounds that perhaps did not volatilize as readily as the volatile materials used in the AEERL study of liquid wastes on sorbents.(7) This would mean that they were less likely to volatilize and deplete the oxygen in the kiln atmosphere when batch charged. If the waste did not have a tendency to form transients in the first place, it would be all the more difficult to detect a difference in transient emissions.

Third, means may not have been available to adequately detect transient emissions once they formed. The AEERL studies indicated that four different measurements, THC peak height, THC peak area, CO level and particulate filter weight needed to be used to adequately detect transient emissions since no one measurement is adequate for all wastes. Even though we attempted to measure THC, we did not detect that many THC peaks. Stripchart recordings of CO emissions provided the only data available on transient emissions. The AEERL studies indicated that CO was not always the best indicator of transients, especially for those compounds, like toluene, which tended to form soot under oxygen deficient conditions. In those situations, particulate filter weight was considered the best measurement of transient emissions.(10) The polycyclic aromatic hydrocarbons in the waste used for the demonstration were structurally similar to toluene and may be anticipated to form soot in oxygen deficient conditions. Measuring particulate filter weight might have been a better way to detect and measure these emissions. Unfortunately, the only EPA method approved for particulate measurement is EPA method 5. This method requires measurement of the stack over a period of hours. This is entirely too long since transient emissions occur over a period of, at most, minutes.

For more information on these studies contact

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Research Triangle Park, North Carolina 27711
(919) 541-5792

D.4 The Use of an Oxygen Burner at Denney Farm

This case study summarizes the use of an oxygen burner on the EPA's Mobile Incineration System (MIS) at an extended field demonstration at the Denney Farm site near McDowell, Missouri.

Before proceeding, it is important to note that the information presented in this section is preliminary in nature. While the field demonstration at Denney Farm has been ongoing for several years, the data gathered during this period has not yet been analyzed and formally reported on. Reports on this project should be forthcoming soon, however, since the field demonstration of the MIS will end in 1989.

Preliminary conclusions indicate that the use of this burner on the MIS significantly improved the efficiency of the cleanup effort at Denney Farm in three ways. First, it may have helped to eliminate several operational problems with the MIS. Second, it may have helped to increase the hourly waste throughput rate possible with the MIS. Third, as a result of the first two improvements it significantly reduced the cost of the cleanup at Denney Farm. After a brief description of the MIS and of the burner, the ways in which its use improved the efficiency of the cleanup of the Denney Farm site will be discussed in more detail. Finally, the relationship between these results and the results obtained during the SITE program will be discussed.

D.4.1 Description of the Mobile incineration System and Oxygen Enhanced Burner

Figure D-l is a block diagram of the MIS. The MIS is a transportable incineration system consisting of a 2343 KW (8MMBTu/hr)rotary kiln, a secondary combustion chamber allowing for 2 seconds residence time, a cyclone, quench, wet electrostatic precipitator and a scrubber. The cyclone is located between the kiln and secondary combustion chamber and is needed to remove soil particles which have been entrained in the kiln atmosphere.

Since 1985, the MIS has been located at Denney Farm burning soil contaminated with dioxin from

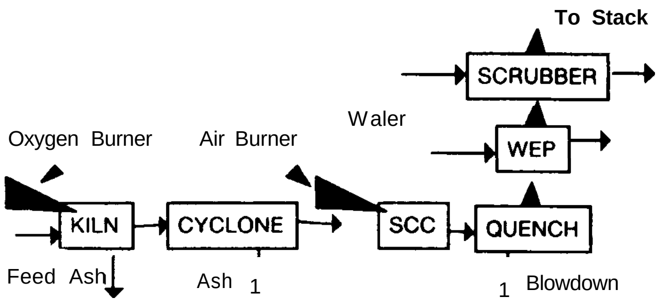

Figure D-l. Block diagram of MIS system.

eight sites in Southwest Missouri. Thus far 3.2 million kg (7 million lb) of soil has been treated. (11) The soil has a relatively low heating value of 465 kJ/kg (200 BTU/lb).

From 1985 to 1986 the MIS successfully decontaminated the dioxin bearing soil at a throughput rate of 2000 lb/hr. Unfortunately, the tine particulate matter contained in the soil tended to become entrained in the combustion gasses in the kiln and subsequently settled out in the secondary chamber. Enough material became entrained in the combustion gas to build up to significant levels in the SCC. This resulted in operational problems which forced shutdowns every few days so that the secondary chamber could be cleaned out.

During an extended period of downtime, several modifications were made to the MIS in an effort to increase both throughput and online time. During this period an oxygen burner, was installed on the rotary kiln of the MIS. A conventional air burner continued to be used on the afterburner.

This burner is an oxygen burner that replaces all of the combustion air with oxygen. By displacing nitrogen in the combustion air stream, an oxygen burner reduces the volume of combustion gas required to incinerate solid waste. This can enable more low BTU solid waste to be incinerated since combustion gas volumes and, hence, velocities are also reduced. Several design features included with the burner are intended to alleviate operational problems associated with oxygen enriched combustion. Two design features are intended to alleviate the high NO_x emissions that often accompany oxygen enhanced combustion. First, the burner replaces all of the combustion air by oxygen. The only air, and therefore nitrogen, that enters the primary chamber, where the burner is mounted, is air that leaks around the rotary kiln seals. By limiting the amount of nitrogen available, the amount of NO_x that can form is also limited. Second, the burner is designed to entrain combustion gasses into the flame envelope. This is believed to reduce flame temperatures. Since high flame temperatures increase NO_x formation, reducing these temperatures reduces NO_x formation.

The burner was provided with a feedback process controller which is designed to maintain a constant oxygen level in the kiln based on oxygen readings taken at the kiln exit. This design feature was intended to help to reduce the transient emissions that occur when solid waste is batch charged to a rotary kiln.(12) A more detailed description of the burner is provided

It was hoped that by installing the burner with the above mentioned design features, waste throughput rates could be increased and operational problems could be minimized. This would make the cleanup at Denney Farm more efficient and less costly.

D.4.2 Throughput Increases

Use of the burner enabled the feedrate of soil to be double from 2000 to 4000 lb/hr. A successful trial burn was conducted at this elevated feed rate and the MIS permit was adjusted to allow for this increased throughput. (11)

D.4.3 Particulate Entrainment

While specific data concerning particulate carryover are not available at this time, experience indicates that particulate carryover was reduced after the addition of the burner. A cyclone separator was installed between the kiln and SCC at the same time that the burner was installed, however, and this modification may have been largely responsible for reductions in particulate carryover. Nevertheless, it is plausible that the installation of the burner helped to reduce particulate carryover. This is because, as mentioned earlier, the use of oxygen reduces combustion gas volume, and velocity, by displacing nitrogen. The linear velocity of the combustion gas at the kiln exit was reduced from (calculated) 8 feet per second to 3.3 feet per second. (11) Less particulate entrainment would be expected with reduced gas velocity.

D.4.4 NO_x Levels

Apparently, NO_x levels did not increase much as a result of the use of the burner. NO_x levels are continuously measured during the operation of the MIS. Although all of this data has not been analyzed yet, NO_x levels recorded during the trial burn conducted with the burner were between 54.6 and 138.3 ppm at 15 percent CO_2. During an earlier trial burn conducted before installation of the burner the NO_x levels were between 126 and 166 ppm at 11 percent CO_2.(11) During a trial burn, air in-leakage is minimized by preventative maintenance conducted prior to the start of testing. On a routine basis, NO_x levels would be expected to be higher than those recorded during a trial burn.

D.4.5 Transient Emissions

Like American Combustion, the manufacturer of this burner also claims to reduce transient emissions through use of their oxygen burner. Although stripchart recordings of operational data exist for both operation with and without the burner, these data have not yet been analyzed to determine if there is a statistically significant difference in the frequency or level of transient emissions produced with and without this burner. Even though it is plausible to presume that maintaining a constant oxygen level in the kiln through the use of a feedback controller would reduce transient emissions caused by momentary oxygen depletion, it is not possible to draw any conclusions on this matter without the above mentioned comparative analysis.

D.4.6 Economics

The economics of oxygen usage in this situation are also favorable. The cleanup effort at Denney Farm costs roughly the same whether or not waste is processed. The increases in throughput and decreases in downtime have reduced the estimated time on site. As a result, savings from this reduction have more than offset the added cost of the burner and oxygen.

D.5 Integration of These Results with Those of the SITE Program

The use of oxygen on the MIS at Denney Farm was a very effective application of this technology for three reasons. First, the installation of oxygen was intended to correct operational problems and not to correct design flaws in the incinerator. Apparently, installation of the burner did help to correct operational problems that were increasing MIS downtime.

Secondly, the waste which was to be treated included low heating value wastes. Large increases in throughput are possible for these wastes when oxygen is used.

Thirdly, the situation in which oxygen was used was a temporary situation which involved very high operational expenses. Throughput increases and increases in online time ultimately reduce the time required for the cleanup and the unit cost for processing waste. This significantly reduces expenses. Thus, the expenses associated with the use of oxygen are more than paid for by savings resulting from reduced time on site.

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