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EVALUATION OF ON-SITE INCINERATION FOR CLEANUP OF DIOXIN-CONTAMINATED MATERIALS

by

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ABSTRACT

The Environmental Protection Agency's (EPA) Mobile Incineration System (consisting of a kiln, secondary combustion chamber, and air pollution control unit, each individually trailer-mounted, and a separate trailer fitted with continuous stack gas analysis capabilities) was rigorously tested in 1982-1983 using PCB-contaminated liquids and other chlorinated organic fluids. Destruction and removal efficiencies of at least 99.9999% were consistently attained at a heat release of 10 million Btu/hr. Based upon these performance data, a project was initiated to evaluate the technical, economic, and administrative viability of on-site incineration of dioxin-contaminated materials in southwest Missouri. During 1984, the system was extensively modified for field use. Solids shredding, conveying, and weighing units were performance-tested in Edison, NJ, with a wide variety of uncontaminated soils and other solid wastes. Additionally, permit documentation, operating and safety protocols, site modification planning documentation, and a risk assessment for the planned trial burn in Missouri were prepared. An aggressive public information activity was conducted by EPA Region VII to disseminate planning and permitting information to Missouri residents.

Simultaneously, laboratory and pilot plant studies were carried out to establish optimum kiln conditions for decontamination of soils by fully volatilizing the organic contaminant, i.e., dioxin. These studies indicated that the conditions necessary to decontaminate soils thermally could be achieved in the kiln. Previous laboratory efforts by others established that dioxins could be destroyed using time, excess air, and temperature conditions achievable in the secondary combustion chamber (SCC) of the EPA system. The EPA system was judged to be more than adequate for detoxifying dioxin-contaminated solids and liquids, and could be reasonably expected to achieve a successful dioxin trial burn. Accordingly, the system was transported to the Denney Farm site in McDowell, Missouri.

From January to March 1985, extensive field shakedown activities were conducted, followed by a trial burn on dioxin-contaminated liquids and solids in April. Results indicated that destruction and removal efficiencies exceeding 99.9999% were achieved for 2,3,7,8-TCDD; no products of incomplete combustion were detected. Additionally, the kiln ash and process wastewater byproducts were shown to be "dioxin free" and in accordance with guidelines proposed by EPA's Office of Solid Waste.

A field demonstration is currently underway and a further trial burn on solid Resource Conservation and Recovery Act- (RCRA-) and Toxic Substances Control Act- (TSCA-) designated materials will be conducted during the Spring of 1986. This paper will present a detailed discussion of the field application of the EPA Mobile Incineration System for destruction of dioxin-contaminated materials at the Denney Farm site.

INTRODUCTION

The continued discovery of abandoned hazardous waste sites as a result of Superfund investigations has placed increasing pressure on the US Environmental Protection Agency (EPA) to find alternate solutions for treating and disposing of toxic and hazardous wastes. The decreasing availability of landfill sites and the increasing public opposition to toxic and hazardous waste transport have added to the pressure. The treatment and disposal problem is particularly acute in the case of the highly toxic dioxin isomer 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). In recognition of these difficulties, EPA's "Dioxin Strategy" (November 28, 1983) indicated that high-temperature incineration is a potential dioxin treatment method warranting further evaluation by the Office of Research and Development (ORD).

A promising, publicly acceptable approach to waste site problems is the use of mobile or transportable cleanup systems that can be brought to a waste site, used to treat or destroy the hazardous materials, and then removed from the site. Public objections are reduced because there is neither the creation of a permanent waste disposal site to which other wastes could be brought nor the continuing transport of wastes through a community.

Mobile incineration is a currently available, on-site cleanup technology that is quite promising. High-temperature incineration is an acceptable method for the destruction of hazardous substances cited under the Resource Conservation and Recovery Act (RCRA) regulations and of PCBs identified by the Toxic Substances Control Act (TSCA) regulations.

Accordingly, the Releases Control Branch (RCB), a component of ORD's Hazardous Waste Engineering Research Laboratory (HWERL), at the request of EPA Region VII, embarked on a field validation project to evaluate the existing EPA-ORD Mobile Incineration System (MIS) for on-site treatment and disposal of toxic and hazardous wastes, particularly soils contaminated with 2,3,7,8-TCDD. This project is part of an ongoing Superfund-sponsored program to evaluate and promote the commercialization of processes, methods, and prototype devices for on-site cleanup of Superfund sites. Specifically, the goals of this project are to evaluate the technical and economic feasibility of the Mobile Incineration System, establish procedures for obtaining Federal, state, and local permits, and gauge the reactions of the public to the use of this system. This paper is an interim report on the evaluation of incineration for on-site treatment of hazardous substances and dioxin-contaminated materials.

Laboratory and pilot-scale work to determine the treatability of dioxin-contaminated soils in the MIS proved very promising. As a result, the MIS was prepared for field operations to conduct a very carefully controlled trial burn on dioxin-contaminated liquid and solid materials at the Denney Farm site in southwestern Missouri. Subsequently, field validation tests on a variety of dioxin-contaminated feeds began in July, 1985. The field work should be completed during the winter of 1986 and a detailed final report will be available thereafter. All documentation will be publicly available.

The final report will include detailed descriptions of the activities of this project and detailed laboratory study information on the MIS, such as the minimum times and temperatures for thermally removing dioxins from soils. Detailed analyses of lessons learned from the field operations with the MIS will be provided. The report will include evaluations of the technical, economic, and institutional viability of on-site incineration, including detailed total and unit cost data and the identification of permitting problems. The report will also contain an annotated index to the additional documentation arising from or related to this project, including (1) the detailed permit application materials for RCRA, TSCA, and National Environmental Policy Act

(NEPA); (2) the delisting petition; (3) risk assessment documentation; (4) detailed operation and maintenance manuals for the MIS; (5) safety manuals for field operations; (6) detailed plans and specifications for constructing the MIS (including detailed cost estimates); (7) detailed plans and specifications for the field installation; (8) detailed trial burn reports arising from the liquids and solids trial burns; and (9) a feasibility study on a modular, transportable incineration system. All documentation will be publicly available through the National Technical Information Service.

BACKGROUND

The Mobile Incineration System consists of a refractory-lined rotary kiln, a secondary combustion chamber (SCC), and air pollution control equipment mounted on three heavy-duty semi-trailers. Monitoring equipment is carried by a fourth, smaller trailer. Other ancillary equipment is assembled at the site, as needed. A detailed description of the Mobile Incineration System has been previously published (1-4).

LIQUID TRIAL BURN

The ability of the MIS to destroy toxic and hazardous liquid organic wastes while complying with applicable Federal and state regulations was demonstrated by carrying out a Liquid Trial Burn of five tests conducted in three phases from September, 1982 through January, 1983 at the EPA facility in Edison, NJ. The tests evaluated the ability of the MIS to destroy tetrachloromethane (carbon tetrachloride), dichlorobenzene, trichlorobenzenes, tetrachlorobenzenes, and PCBs while controlling the emissions of HCl and particulate matter. A total of 25 test runs was conducted during which the incinerator's operating conditions were monitored and an extensive sampling and analytical program was conducted. Federal and/or state observers were on site throughout the entire trial burn to ensure that the incineration system was operated safely and in accordance with the trial burn permits.

The high combustion and destruction efficiencies measured during the liquid trial burn clearly demonstrated that the EPA Mobile Incineration System is an effective device for the destruction of hazardous organic material. In fact, the level of combustion and destruction reported was essentially based on analytical limitations of measurements rather than on the actual finding of hazardous components in the stack emissions. The results of the trial burn indicate that the system met or exceeded all applicable Federal requirements for incineration systems (Table 1). The system was then deemed to be ready for field operations on liquids.

MISSOURI PROJECT DESIGN

The first step toward field operations was selection of a site for the demonstration. Agreements were reached in April, 1984 to operate the Mobile Incineration System on the Denney Farm near McDowell, MO, where over 90 drums of buried dioxin-contaminated wastes had been excavated and stored in a diked shelter. A second covered concrete basin on the site contained over 240 cubic yards of soil that had become contaminated when the buried drums leaked. The site was considered desirable by Syntex (current owner of the wastes), Region VII, the Missouri Department of Natural Resources (MDNR), and HWERL because of its remoteness -- approximately one mile from a public road, and in a rural area.

A wide variety of dioxin-contaminated wastes, such as soil, liquids, drums, trash, and chemical solids, were on the site and could be used to demonstrate the versatility of the Mobile Incineration System. A variety of nearby soil types could be used to demonstrate that incineration could decontaminate any dioxin-containing soil found anywhere in Missouri.

The overall project design for evaluation of the MIS in Missouri included the following elements, each of which is discussed in greater detail below:

TABLE 1. RESULTS OF LIQUID TRIAL BURN

Parameter	Reg. Limit	1[a]	2[b]	3[c]	4[d]	5[e]
Kiln						
Temp., °C		900	890	900	980	960
SCC						
Temp., °C	1200+/-100[f]	1180	1180	1190	1220	1250
O_2, %	3%[f]	7.5	8.8	8.0	7.2	6.9
Retention time, sec	2[f]	1.96	2.10	2.06	1.97	2.03
Combustion efficiency, %	99.9[f]	99.999	99.999	99.999	99.999	99.999
HCl removal efficiency, %	99[g]			99.95	99.98	99.99
DRE[i]						
CCl_4	99.99[g]			99.99996		
DiClB	99.99			99.99998		
TriClB	99.99				99.9998	99.99993
TetraClB	99.99				99.9994	99.9998
PCB	h				99.9998	99.99991
Particulate, mg/Nm^3 @ 7% O_2	180[g]	6.9	22.1	64.9	35.2	42.7

a Test 1 Fuel oil only - baseline - all results average of 3 test runs
b Test 2 1.2% Iron oxide in fuel oil for particulate test
c Test 3 21% CCl_4, 29% DiClB in fuel oil
d Test 4 11% Askarel in fuel oil
e Test 5 39% Askarel in fuel oil
f TSCA
g RCRA
h No DRE limit for liquid PCB
i CCl_4 = tetrachloromethane; DiClB = o-dichlorobenzene; TriClB = trichlorobenzene; TetraClB = tetrachlorobenzene; PCB = polychlorinated biphenyls.

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1. Planning and Permits
2. Legal and Public Relations Activities
3. Modifications to the MIS
4. Laboratory and Pilot Studies
5. Operating Procedures and Operator Training
6. Site Preparation and Logistics
7. Field Shakedown and Preliminary Testing
8. RCRA/TSCA Trial Burn
9. Field Demonstration
10. Final Reports
11. Future Use

PLANNING AND PERMITS

This activity included the preparation of: detailed contractors work plans; applications for Federal permits (Clean Air Act, Toxic Substances Control Act, National Environmental Policy Act, Resource Conservation and Recovery Act) and State permits (MDNR); delisting petitions for assuring the cleanliness of MIS solid and liquid byproducts for both the trial burn (Table 2) and the field demonstration; and a risk assessment of MIS operations on dioxins and a health survey required by MDNR (the risk assessment and health survey documents were prepared by ORD's Exposure Assessment Group).

LEGAL AND PUBLIC RELATIONS ACTIVITIES

Legal Arrangements

The activities conducted at the Denney Farm site have required contractural agreements between the two principal parties, namely, EPA and Syntex Agribusiness, Inc. (Syntex) and between the EPA's operating contractor, IT Corporation, and both of the principal parties. Three agreements were prepared, each of which was interdependent.

Additionally, an access agreement with the landowner, the James Denney family, was modified to enable operations to take place at the farm. These complex arrangements among Syntex, IT, and the Denneys were negotiated by Region VII's legal counsel with technical inputs from EPA's HWERL Releases Control Branch and IT Corporation.

Public Relations Activities

As a result of an agressive public information effort conducted by Region VII, the Mobile Incineration System was welcomed in Missouri and was operated in a favorable atmosphere of increasing public acceptance of incineration. The activities included press conferences, presentations to civic organizations, an open house and tour of the site installation prior to operations, the required RCRA/MDNR permit public hearing, and a "technical day" during which preliminary trial burn data were publicly released and a site tour conducted for interested parties. These activities were critically important to the overall success of the project, and received the personal attention of the Regional Administrator -- a key element in the success of the project.

MODIFICATIONS TO THE MIS

Several changes were made to the original MIS design, including general modifications affecting the refractory; the burner controls; the stack gas monitoring system; the electrical system; and the design, specification, procurement, installation, and shakedown of a solids feed system. Both hot and cold tests were performed.

The main purpose of the cold test was to evaluate the factors that affect the retention time of solids in the kiln, including rotational speed and inclination angle of the kiln, type and rate of feed of material to the kiln, and the use of flights at the inlet and heat-economizer chains at the outlet of the kiln. Based on the observations made during the cold test, design and operational changes were made to improve the flow of solids through the kiln.

As a result of the hot tests, it was concluded at the time that the kiln capacity was limited by the solids feed system and that particulate emissions would not be a problem. The study suggested changes in operating procedures, such as operation of the kiln in a sloped position, decreasing the rotational speed, and operating with less excess air.

TABLE 2. DELISTING PARAMETERS, FOR THE TRIAL BURN ONLY, CONSIDERED BY THE MISSOURI DEPARTMENT OF NATURAL RESOURCES AND THE US ENVIRONMENTAL PROTECTION AGENCY

A. Per 40 CFR 261 Subpart C

	Ash Solids	Scrubber Waste Liquids
Ignitability	NA[a]	NA[b]
Corrosivity	pH = 2.0-12.5	pH = 2.0-12.5
Reactivity	Not reactive with water	Not reactive with water
EP Toxicity	As per 40 CFR 261.24, Table 1, and App. II, except mercury[c]	ICP scan-heavy metals, except mercury as per Table 1[c]

B. Specific Substances

Toxic Constituent	Concentration Solids	Concentration Scrubber Water
Dioxins/Dibenzofurans[d]	1 ppb	10 ppt
2,3,4-Trichlorophenol	100 ppm	10 ppm
2,4,5-Trichlorophenol	100 ppm	10 ppm
2,4,6-Trichlorophenol	1 ppm	50 ppb
2,5-Dichlorophenol	350 ppb	15 ppb
3,4-Dichlorophenol	100 ppm	10 ppm
2,3,4,5-Tetrachlorophenol	1 ppm	50 ppb
2,3,4,6-Tetrachlorophenol	1 ppm	50 ppb
1,2,4,5-Tetrachlorobenzene	100 ppm	10 ppm
1,2,3,5-Tetrachlorobenzene	100 ppm	10 ppm
Hexachlorophene	200 ppm	5 ppm
Polychlorinated Biphenyls	2 ppm	1 ppm
Benz(a)pyrene	5 ppm	10 ppb
Benz(a)anthracene	5 ppm	10 ppb
Chrysene	50 ppm	1 ppm
Dibenzo(a,h)anthracene	5 ppm	10 ppb
Indeno(1,2,3-c,d)pyrene	5 ppm	10 ppb
Benz(b)fluoranthene	5 ppm	10 ppb

[a] The ash would not be ignitable after having passed through a kiln and having reached approximately 750°C at the time of discharge.

[b] The scrubber wastewater is not considered ignitable.

[c] Analysis will be for the following metals: arsenic, barium, cadmium, chromium, lead, nickel, selenium, silver.

[d] Weighted average of tetra-, penta-, and hexa-isomers using weighting factors related to toxicity.

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Upon completion of the hot tests, the kiln and SCC were opened and inspected. The examination revealed that a large amount (up to 9 in) of solids had been carried over into and deposited at the front end of the SCC. Although some carryover had been expected, the quantity and location of the deposits were not. It appeared that the "spin vane," a device designed to create swirling turbulence in the gas stream and thus enhance combustion efficiency, was a major factor in the deposition of particulates at the front end of the SCC. At that time, it was decided to make no changes in the spin vane, but to carefully monitor the operations and frequently check for the presence of solids buildup in the SCC. A number of modifications were made to correct several minor problems, and a second hot test was run to ensure that these problems had been corrected. Following the hot test, the system was dismantled and prepared for shipment to Missouri.

LABORATORY AND PILOT STUDIES

The goals of these studies were to determine whether the objective of decontaminating the soil to less than 1 ppb dioxin was feasible, given the operating limits of the MIS, and to develop recommended operating conditions for the demonstration run.

Laboratory Studies

In treating contaminated soil with an incinerator or other thermal treatment device, two processes can achieve decontamination: volatilization with resulting vapor separation followed by gas phase combustion, and thermal decomposition within the solid soil matrix. The mechanisms that determine the relative importance of these "treatment" processes are volatilization, diffusion, and thermochemical reactions, each of which occurs at different temperature-dependent rates.

Theoretical and empirical studies of volatilization and diffusion of chemicals within a static soil at normal environmental conditions are not directly translatable to treatment under dynamic, high-temperature conditions, such as exist in a rotary kiln. Thermochemical behavior of specific chemicals has been studied to a limited extent; estimates of thermal stability and decomposition kinetics are important in establishing guidelines for incineration performance requirements. However, these studies have dealt with gas phase reactions and pure (single component) systems. Also, alterations to the chemical and physical characteristics of the primary natural organic components and of certain inorganic constituents of soil occur at temperatures far lower than typical incineration conditions. The complexity and variability of a soil and its interaction with specific chemicals frustrate any straightforward analysis of the effect of typical incineration conditions on a particular contaminated soil.

Prior to the beginning of laboratory treatability tests, information on the soils at the various confirmed dioxin-contaminated sites in Missouri was collected. From this list, four sites were selected as candidates for treatment. Two of these soils, Piazza Road and Denney Farm, were selected for laboratory treatability testing since they covered a wide range in pH, conductivity, organic matter, and particle size distribution.

Samples of these two soils were prepared for laboratory treatability testing by air drying, screening through a 2-mm (10-mesh) sieve, and blending thoroughly. Analysis for 2,3,7,8-TCDD in triplicate aliquots of each prepared soil showed relative standard deviations of less than 7%. The initial average 2,3,7,8-TCDD concentration was 563 ppb for Denney Farm and 338 ppb for Piazza Road soils. These relatively high levels were advantageous in enabling the maximum range of treatability to be investigated.

The laboratory experimental program was divided into three series of separate treatability tests with a total of 31 tests. The first series, using principally Denney Farm soil, explored broad ranges of residence time and temperature to define the appropriate combination of conditions that would produce desired treatment efficiencies, as measured by a final 2,3,7,8-TCDD concentration of 1 ppb or less. The second series used a fixed time-temperature condition and evaluated the effect of soil type (Piazza Road vs Denney Farm), initial soil moisture content, and gas phase composition on treatability. The final series included selected additional treatment conditions to fill in data gaps and also several special tests in which 5 cm "cubes" of Piazza Road soil were prepared and subjected to various test conditions.

In the second series of tests, there was no significant correlation between treatability and either moisture or atmosphere. Soil type had an influence, but this was determined to be due primarily to the temperature increase that occured with Piazza Road soil, presumably as a result of exothermic reactions of the organic matter that was present at much higher levels than in the Denney Farm soil. Once the effect of temperature was factored into the statistical evaluation, the true effect of soil type was relatively minor.

In the third series of tests, using 5-cm cubes, the substantial lag in achieving the target test temperature within the core was due largely to the drying process. The evaporation rate of the initial 20% moisture content from the cube is dependent on the heat and mass transfer characteristics of the cube and the external gas temperature, which in the MIS kiln would be higher than 500°C. Another test performed with the furnace temperature at 800°C resulted in a significant reduction of heat-up time of the cube; the core reached 400°C in 19 min vs 36 min in the 500°C furnace. Separate analyses for 2,3,7,8-TCDD of the core and exterior sections of the treated cubes demonstrated that 1 ppb could be achieved throughout and illustrated the effect of the transient temperature condition. At an 800°C furnace temperature, a total residence time of 33 min resulted in non-detectable (less than 0.1 ppb) 2,3,7,8-TCDD concentration, whereas a shorter residence time of about 20 min showed more than 7 ppb 2,3,7,8-TCDD remaining in the core section. The test at 500°C furnace temperature provided for 40 min for treatment and resulted in approximately 1 ppb throughout the cube.

A linear regression analysis of the treatability data for Denney Farm soil produced two different mathematical relationships to predict the final 2,3,7,8-TCDD concentration at different time-temperature conditions. The simplest of these expressions shows a logarithmic dependence of 2,3,7,8-TCDD concentration on the "time integral of vapor pressure," which is defined by integrating the calculated vapor pressure of 2,3,7,8-TCDD using the specific temperature-time profile. The vapor pressure can be estimated using Antoine constants developed by Schroy et al. experimentally (personal communication). Figure 1 and Table 3 based on this expression depict the time-temperature requirements to achieve different decontaminations of the Denney Farm soil initially containing 563 ppb 2,3,7,8-TCDD.

Other observations made during the laboratory program offered insight into the thermochemical phenomena that occur in soil at incineration temperatures. Agglomeration, slagging, or fusion of soil particles was not observed for either soil.

The cubes developed cracks and became friable, particularly within the core. Weight-loss measurements and visual inspection indicated that decomposition of soil organic matter could lead to highly variable results, depending on the exposure or accessibility of the soil particles. In general, weight loss in excess of that attributable to free moisture and organic matter was 1-9%. Loss of bound moisture from the clay mineral content of these soils is suspected to be the primary source of this excess loss. Higher temperatures resulted in greater weight loss, and Piazza Road soil tended to have higher losses. However, the cube experiments using Piazza Road soil showed lower non-moisture-related weight loss than the experiments using a loose, thin layer of the same soil, and the interior of the cubes turned black.

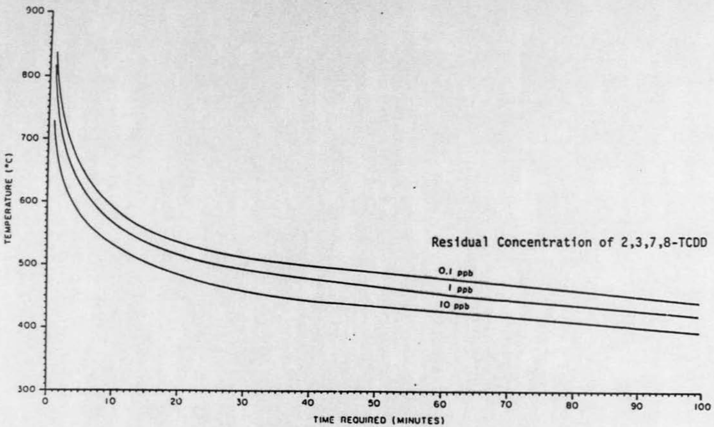

Figure 1. Effect of time and temperature on removal of 2,3,7,8-TCDD from Denney Farm soil.

TABLE 3. TIME-TEMPERATURE EFFECTS ON REMOVAL OF 2,3,7,8-TCDD

Nominal Test Temperature (°C)	Time at Test Temperature[a] (min)	Soil Type[b]	Residual 2,3,7,8-TCDD Concentration (ppb)
429	0	A	377
430	15	A	60
429	30	A	30.8
428	90	A	10.2
429	90	B	2.86
475	0	A	67
478	15	A	8.4
477	30	A	3.7
479	30	A	3.37/3.30[c]
550	0	A	24
550	0	A	27.5
554	15	A	0.16
616	0	A	0.2
616	15	A	ND (0.08)
616	30	A	ND (0.06)
803	30	A	ND (0.02)
808	30	B	ND (0.04)
803	90	A	ND (0.08)

[a] This time begins when the target test temperature is reached; therefore, zero time is actually six to nine minutes after start of heat-up.

[b] A: Denney Farm Soil; B: Reference Soil.

[c] Analytical duplicate; separate aliquots of treated soil were analyzed.

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Evidently, the significant concentration of organic matter in the Piazza Road soil was partially retained as non-volatile products (char) of thermal decomposition.

The results from the laboratory testing demonstrated that the clean-up criterion of 1 ppb could be achieved at reasonable kiln operating conditions and provided part of the information needed to project the specific treatment regimen (kiln residence time and temperature) for various feed rates and feed conditions for the MIS.

Pilot Testing and Computer Modeling

Pilot-scale experimentation was conducted on uncontaminated Missouri soil from the Denney Farm site. Tests included firing in a pilot-scale rotary kiln; bulk density and screen analysis; dynamic angle of repose, thermogravimetric and differential scanning calorimeter analysis; and soil moisture analysis. These tests were conducted at the Allis-Chalmers research and test center in Oak Creek, Wisconsin on August 28-30, 1984.

The first pilot-scale run was performed at a constant gas temperature of 982°C (1800°F). The gas temperature was maintained throughout the course of the 60-min run by varying the fuel rate at a constant air flow. The initial moisture content of the soil was 19%. Subsequent runs were conducted by maintaining set natural gas and air flow rates throughout the run. The set flow rates were determined from temperature profiles of previous runs and were designed to give the desired steady-state temperatures and excess oxygen levels.

A significant result of the runs was the apparent correlation of soil moisture content with the observed fractionation of soil chunks. In all trials with 19% moisture, complete fractionation was observed, yielding soil particles that were smaller than 2 cm in any dimension. In the single run conducted at 12.3% moisture, slightly less fractionation occurred, although it was similar to the 19% moisture runs. It is apparent that the fractionation mechanism is at least partially dependent on the forces exerted by steam escaping from the soil during heating.

Trials were performed at bed temperatures of up to 1036°C (1897°F), with no slagging or agglomeration observed. This demonstrates that slagging and agglomeration should not occur when the MIS is used to treat Missouri soils. The nine runs of the pilot test provided data to evaluate the heat transfer computer program, which contains standard constants for the various heat transfer modes in a rotary kiln. By operating the kiln at various steady-state conditions, a data base on the time-temperature profile of Missouri soil in the batch kiln was obtained. The heat transfer program could be modified to predict this profile and the difference between the observed and predicted results used to more closely model actual conditions.

The computer program calculates kiln solids capacity and retention time if all other variables are specified. For this study, the kiln capacity was set by the height of the corbel at the feed end of the kiln. More correctly, the height of the material at the kiln entrance cannot exceed the height of the corbel. The same height at the feed end of the kiln can result in a variety of mass-flow kiln capacities, depending on the kiln slope, rpm, etc. According to the program, this variation was not great; the calculated kiln capacities varied from 6-8% of the kiln volume. This agreed with earlier tests that indicated a maximum kiln capacity of 7% of the kiln volume.

The mass-flow computer program was run for a matrix of kiln slopes, rotational speeds, and feed rates. As the kiln slope increases, its capacity also increases as the result of a more consistent solids depth along the length of the kiln. For a kiln with a low slope, the slope of the solids provides the driving force for solids flow. In a kiln with a steeper slope, the kiln slope provides the driving force, allowing for more consistent solids depth. It was therefore recommended that the kiln be operated at its maximum slope.

For the MIS on a level pad, this slope is approximately 2-3%.

Flights along the kiln length increase solids throughput at a given slope and rpm. This limits the minimum feed rate and reduces the effective kiln length. For these reasons, flights have been removed from the length of the kiln. However, the eight flights at the feed end of the kiln, which prevent spillage over the corbel, remain.

OPERATING PROCEDURES AND OPERATOR TRAINING

Operating and safety procedures for the Mobile Incineration System were updated based on the new solids feed capability, the experience gained during previous operations, the special considerations required for handling dioxins, and the site-specific requirements for Missouri. The operating and safety manuals were revised to incorporate the new procedures. All operators and other key personnel went through an extensive training course that included system operation, operating safety, and other site safety procedures.

Further, an industrial hygienist remained onsite during the Dioxin Trial Burn. He observed and corrected operating and sampling practices, conducted personnel monitoring, and made daily site safety inspections. All site subcontractors, government observers, and visitors to the site for any length of time were given site-specific safety presentations.

SITE PREPARATION AND LOGISTICS

Site Planning and Preparations

Upon selection of the specific site for the Mobile Incineration System demonstration, detailed engineering and design were commenced to satisfy geographical, operating, and permitting requirements.

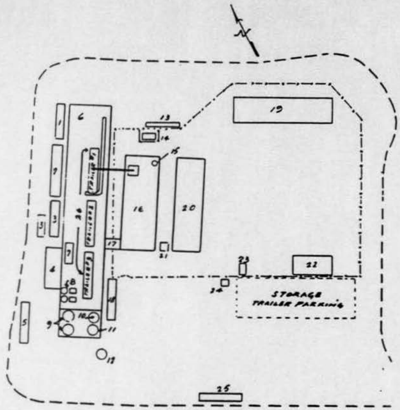
To establish geographical requirements, a site survey was conducted that considered grades, elevations, property boundary lines, access routes, and existing road conditions. Maximum consideration was given to leaving "untouched," to the greatest extent possible, the natural contours, vegetation, and woodlands. The final site layout is shown in Figure 2.

The physical dimensions of the solids feed handling system and the location of the contaminated materials in the Drum Storage Building (Figure 2) determined the relative location of the incinerator. The concept was to maintain the incinerator in a clean area while violating the integrity of the secure, contaminated boundary (fenced area around existing buildings) as little as possible. This would contain the contaminants within the incinerator system and prevent any increase in contaminated area. All the equipment was placed on a 4-in-thick, poured concrete pad surrounded by a 6-in-high concrete dike to facilitate containment and clean-up in the event of a spill or leakage of contaminated material in the incinerator area.

The remote, undeveloped nature of the site necessitated installation of a deep well and the water supply system required for operations. Fuel oil, propane, water, and wastewater tanks were installed. Portable office and storage trailers were used extensively to minimize the construction of fixed structures. The MIS was enclosed in a 40 X 225 ft prefabricated shed building for personnel and equipment weather protection. A guard service company was contracted to provide site security and to control access of personnel during operations. A log was kept for all persons as they entered and left the site. Six underground telephone lines were installed; the telephones were located throughout the site. For backup emergency communications, two FM radio base stations were installed that operated on the Monett, MO, police department frequency.

Transportation and Setup of Incinerator

The MIS was transported to and set up on the Denney Farm site in mid-December, 1984. In addition to the four main trailers of the incineration system, five other trailers were required, both to complement the operation (e.g., a personnel decontamination trailer) and to transport the auxiliary equipment and spare parts.



LEGEND

SYM.	DESCRIPTION
1	Office trailer
2	Operations trailer
3	Sampling and Analytical trailers
4	Utility equipment and storage area
5	Spare parts and storage trailer
6	Mobile incinerator building
7	Stack monitoring trailer
8	3 Clarifier tanks with filtration skids
9	2 15,000-Gal wastewater storage tanks
10	7,500-Gal process water storage tank
11	7,500-Gal alkaline storage tank
12	11,000-Gal fuel oil storage tank
13	HEPA filter
14	Hydraulic skid for shredder
15	1,000-Gal waste oil feed tank
16	Drum storage building (Syntex)
17	Personnel decon. station
18	Operating and Sampling crew change trailer
19	Microbiological degradation building No. 2 (Syntex)
20	Microbiological degradation building No. 1 (Syntex)
21	Water heater shed (Syntex)
22	Equipment decon. building (Syntex)
23	Personnel decon. shed (Syntex)
24	Guard shed (Syntex)
25	EPA conference trailer
26	Mobile Incineration System

Figure 2. Site layout for MIS at Denney Farm.

Additional support equipment was either provided by Syntex, purchased, or leased to complete the incineration system setup. Syntex provided four storage tanks ranging from 10,000-15,000 gal capacity, to be used for makeup water, alkaline solution, and wastewater storage. Seven trailers were leased to provide lunch and rest space for the operators, office and work space, and shelter for the site guard service. Other leased auxiliary equipment included such items as forklifts, a backhoe, power generators, air compressors, storage vans, and space heaters. Fuel oil and propane storage tanks were furnished by local suppliers.

FIELD SHAKEDOWN AND PRELIMINARY TESTING

Final preparations, component checks, and on-site personnel safety training were completed by early January, and the incineration system was then started up with fuel oil to check its performance after transport from New Jersey. The startup proceeded relatively smoothly and the system was brought to operating temperature within two days; however, the solids feed shredder jammed during below-freezing temperatures shortly after being started with clean Missouri soil. The failure was caused by a broken spline drive resulting from the high viscosity of the hydraulic drive fluid and differential contraction of internal motor components, both resulting from the subfreezing temperatures.

Extremely cold weather (-15°F, -50°F wind chill) that lasted for several days created a number of problems with freezing water lines and gelled fuel oil; the operating crew spent much time struggling to keep the system operating. The incineration system was restarted early in February, but a number of different problems hampered initiation of the trial burns. Most of these problems involved mechanical difficulties, or were weather-related. The mechanical problems were ultimately solved, the ambient temperature rose, and the shredder has performed well ever since.

As part of the startup plan, a blend of 15% by volume sodium sulfate and clean local soil was fed to the incinerator to evaluate whether that specific concentration of salt would cause slagging and ash removal problems in the rotary kiln. The test was conducted because of the potential for incineration of 23 cubic yards of dioxin-contaminated sodium sulfate at the Syntex, Verona, MO, plant. The salt built up as a heavy slag in the kiln; therefore it must be fed at much lower concentrations, if at all, in order to minimize slag build-up in the kiln. (The quantity of soil to be fed during the field demonstration is insufficient to handle all the sodium sulfate at the acceptable low concentration.)

In preparation for Test 1 of the trial burn (see Trial Burn Plan, below), the tetrachloromethane/methanol liquid blend and PCB/hexachloroethane/montmorillonite solids blend were fed to the incinerator. However, before the system could be brought to equilibrium to start sampling, a number of mechanical problems developed, primarily in the quench system of the air pollution control section.

After repairing the quench pump and installing a hydrocyclone in the quench sump (to remove accumulations of fine particulates being carried into the quench system from the SCC), high rates of tetrachloromethane/methanol were successfully fed to the incinerator to verify that the air pollution control system was functioning properly.

Additionally, preliminary stack particulate testing with a high feed rate of chlorine (equal to that scheduled for Test 1) revealed corrosion of the carbon-steel sound attenuator stack section by hydrogen chloride. The high corrosion rate caused fine particles to be emitted from the stack, thus causing the system to exceed RCRA particulate standards. The attenuator was subsequently replaced by a stainless steel stack section so that the system would comply with RCRA when high-chlorine feeds were to be used.

At this time, after consultation with Region VII management and incinerator operating personnel, HWERL decided to defer the high-chlorine trial burn (Test 1) and conduct the Dioxin Trial Burn (Test 2) first. Accordingly, dioxin-contaminated liquids and solids were fed to the incinerator for the first time at the end of February. Additional minor problems were encountered, and the system was shut down for correction. The restart run was conducted with minimal problems and became the first completed Dioxin Trial Burn run.

The February operation was difficult for the operating crew, as well as for the EPA personnel and observers, primarily because of all the minor problems that delayed the testing. Entrained solids carryover from the kiln became a problem because of its accumulation in the secondary combustion chamber in front of the lower of the two fuel oil burners. The mass of solids became a glass-like slag that interfered with the burner operation. The burner was removed each night and the solids that could be reached were removed manually by chipping with a sledgehammer and a steel pipe. When the burner was removed after the completed test run, a large hole was found in the internal spin vane that induces swirling turbulence to the gases that enter the SCC. The Inconel (a high- temperature nickel alloy) vane evidently melted because of flame impingement that resulted when the slag buildup deflected the burner flame onto the vane. Because the vane was regarded as a critical component, the system was again shut down.

After consultation with incineration experts, a plan was developed in March to rebuild the spin vane, make minor operating adjustments, and continue with the Dioxin Trial Burn while carefully observing the solids buildup in the SCC. The plan further called for more extensive modifications during the shutdown period after the trial burn and before the field demonstration.

The SCC was totally cleaned out, the new spin vane was fabricated and installed, and routine maintenance was performed during March. The incinerator was restarted April 1, and three more Dioxin Trial Burn test runs were executed in a period of 4 days. There continued to be some minor problems with the solids feed and with solids carrover, but the runs generally went smoothly. After completing the dioxin test, the Syntex lagoon sludge evaluation, Test 3, was conducted. The sludge was the first combustible solid of any quantity to be fed to the Mobile Incineration System. The test went well but, when the SCC was checked after the test, a large amount of solids was again observed near the spin vane.

RCRA/TSCA/DIOXINS TRIAL BURN

Trial Burn Plan

The purpose of the trial burn is to obtain data, which, when combined with data from the Liquid Trial Burn in Edison, NJ, would verify that: (1) dioxins and other hazardous organic liquid and solid materials are destroyed by incineration in the EPA Mobile Incineration System to a residual ash concentration of less than 1 ppb, and (2) the resulting stack emissions do not pose an unacceptable health or safety risk to the surrounding communities. The trial burn was designed to provide data to support the issuance of the State and Federal permits required for use of the incinerator at the Denney Farm site in southwestern Missouri and to provide sufficient data to enable future use of the EPA Mobile Incineration System on practically any hazardous organic material at Superfund and other hazardous waste sites.

At the Denney Farm site and at other locations in Missouri, dioxins, PCBs, and RCRA-regulated substances are stored or otherwise exist as liquids and solids. Therefore, trial burn data on these materials in both liquid and solid form were necessary for evaluating the performance of the MIS. EPA and State regulatory offices currently require trial burn data on both liquids and solids because of the processing differences between liquids and solids in the kiln of a kiln-plus-secondary-combustion-chamber-type incinerator. In part, this arises because organic liquids can be passed through a burner and directly destroyed whereas solids must first be heated by thermal radiation and by contact with refractory in a kiln to release organic contaminants that are subsequently destroyed. Further, because of the public sensitivity concerning dioxins, a special dioxin trial burn -- as applied to liquids and solids -- was requested by the EPA Dioxin Disposal Advisory Group and the Office of Solid Waste in support of RCRA regulations relating to the destruction of dioxins.

The trial burn program was planned to consist of three tests. The tests each consisted of three replicate sampling runs, i.e., a total of nine sampling periods. However, due to scheduling problems that arose during the trial burn, Test 1 was not executed. Test 1, a burn of PCBs and chlorinated hydrocarbons on montmorillonite soil, will be conducted at the end of the field demonstration. The Trial Burn Plan was extensively reviewed by scientific and regulatory reviewers and formed a major portion of the RCRA/MDNR permit application.

1. Test 1
   A mixture of solid hexachloroethane and montmorillonite (a major source of bentonite) with adsorbed PCBs, will be fed to the rotary kiln. In addition, two liquid streams will be fed to the rotary kiln, one an organic liquid consisting of tetrachloromethane and methanol having a low heat value, and the other an aqueous stream containing a portion of the organic liquid. The objective of this test will be to obtain for the MIS (1) a TSCA non-liquid PCB permit, (2) a RCRA non-liquid permit, and (3) a RCRA liquids permit to allow the incineration of low-heat-value organic liquids and contaminated aqueous liquids. This test will consist of three runs of 8-12 hours each to collect the required 4 cubic meters of stack gas sample.

2. Test 2
   During this test, 2,3,7,8-TCDD-(dioxin-) contaminated soil and dioxin-containing waste liquids were fed to the rotary kiln to demonstrate the Mobile Incineration System's capability of destroying dioxin at the 99.9999% destruction and removal efficiency (DRE) level. This test consisted of four successful runs of 8-12 hours each to collect the required 4 cubic meters of stack gas sample.

3. Test 3
   Bromine-contaminated sludge was fed to the rotary kiln to demonstrate the Mobile Incineration System's capabilities of controlling bromine/hydrogen bromide emissions while incinerating bromine-contaminated wastes. The test consisted of three runs of 0.5 hr each.

Quality Assurance Project Plan

Preparation activities for the trial burn included the preparation of a quality assurance project plan (QAPP) as required of all EPA-sponsored research programs. The QAPP focuses on the details of collecting, handling, and reporting the trial burn data and results. The QAPP also establishes quality criteria to ensure that the trial burn data and results are technically sound and acceptable to regulatory offices. This plan underwent extensive review by technical experts, both inside and outside of the Agency, and by regulatory officials. The QAPP encompasses two separate aspects of the trial burn: the operation of incineration equipment and the collection of routine operating data. The plan also describes in great detail the collection and analysis of special samples associated with the trial burn.

The sampling techniques range from the very simple (e.g., collecting waste water samples for standard analyses) to the very complex (e.g., collecting stack gas samples for measurement of nanogram quantities of 2,3,7,8-TCDD). The sampling and analysis plan also provides all the specific procedures to be used for sample analyses. Standard analytical protocols are used whenever possible, but the determination of 2,3,7,8-TCDD in incinerator effluents requires state-of-the-art analyses to demonstrate the required DRE. The samples were analyzed in two laboratories to provide independent verification of test results. Detailed QA/QC data were sent to the EPA Environmental Monitoring and Support Laboratory in Las Vegas and to Region VII for review.

Dioxin Trial Burn Results

The feed materials for the trial burn consisted of dioxin-contaminated liquid still bottoms and soil for Test 2, and dioxin-contaminated lagoon sediment for Test 3. The still bottoms, originally from a trichlorophenol purification still, were blended with solvents to control the concentation of 2,3,7,8-TCDD within permit limitations. These solutions were analyzed prior to the trial burn to verify the 2,3,7,8-TCDD concentration and to select an appropriate liquid waste feed rate. The dioxin-contaminated soil came from the original Denney Farm trench and had been kept in a covered concrete basin as loose soil. The soil was placed in 55-gallon drums that were subsequently dumped into the solids feed system. The lagoon sediment came from an industrial waste storage lagoon in Springfield, MO, and contained low concentrations of brominated naphthalenes and 1-20 ppb 2,3,7,8-TCDD. This sediment was stabilized with calcium oxide and transferred to the Denney Farm site in 55-gallon drums for processing.

The incinerator operating conditions during the Dioxin Trial Burn were essentially the same as those during the previous Liquid Trial Burn successfully conducted in New Jersey (Table 4). Waste liquids and solids were fed to the rotary kiln. The solids were retained in the rotary kiln, operated at gas exit temperatures of 845^{o} to 955^{o}C, for approximately 30 min before being discharged into drums. The solids achieved approximately 750^{o}C upon discharge. The gases from the combustion of wastes flowed into the secondary combustion chamber where they were heated to 1150^{o}-1230^{o}C. In the secondary chamber, the combustion gases were mixed with excess oxygen (air) (to a control level of 4-7% O_2) and were retained for 2.4 to 3 seconds. (The greater retention time was caused by the operation of the incineration system at low gas flow rates to minimize particulate carryover from the kiln into the SCC.) The combustion gases then passed through three stages of air pollution control equipment used to cool, filter, and remove acid gases (by-products from the combustion of wastes) and particulate matter (primarily from the solid wastes processed). Other process effluent streams (kiln ash, CHEAF mat, and purge water) were collected and analyzed in accordance with delisting guidelines and the Trial Burn Plan to determine whether any hazardous materials were discharged from the incineration system.

The performance of the incinerator during the trial burn was accurately determined by monitoring all feed and effluent streams. The performance criteria for Test 2 were the DRE for 2,3,7,8-TCDD and the particulate emission rate (Table 5). Bromine emission control was monitored during Test 3, and the incinerator demonstrated exceptional performance in destroying organic waste materials. This ability has now been demonstrated on both solid and liquid waste materials. In fact, the incinerator's performance is actually better than that reported since the actual emissions were lower than what is measurable by current sampling and analytical technology. No 2,3,7,8-TCDD was detected in the stack, using state-of-the-art high resolution mass spectrometry. The lowest DRE for 2,3,7,8-TCDD was 99.999973%; the best DRE measured during the trial burn occurred in Test 2, Run 4, which had the greatest analytical sensitivity (Table 6). The DRE for this run was 99.999995%, which was twenty times better than State and Federal requirements. Although the spin vane probably failed prior to Test 2, Run 2, the results meet all permit requirements.

Some problems were encountered with the measured levels of particulates in the stack, with one run of four being somewhat in excess of the RCRA standard of 180 mg/m^3 (@ 7% O_2). This was subsequently attributed to a buildup of submicron-sized particles in the mass transfer scrubber, the last element in the air pollution

TABLE 4. MOBILE INCINERATION SYSTEM OPERATING CONDITIONS

Parameter	Test 2 Average				Test 3 Average
	Run #2	Run #3	Run #4	Run #5	Runs 1, 2, & 3
Rotary Kiln					
outlet gas temperature, °F	1,650	1,600	1,678	1,729	1,587
pressure, in. H_2O vacuum	0.7	0.3	0.2	0.3	0.1
combustion air flow, scfm*	1,029	923	1,177	1,056	1,098
atomization air flow, scfm	79	89	90	89	90
diesel fuel flow, lb/hr	104	45	106	45	60
liquid waste flow, lb/hr	233	236	234	247	0
solid waste flow, lb/hr	1,158	1,363	2,068	1,322	973
ash discharge rate, lb/hr	933	989	1,531	1,105	463
gas residence time, sec	2.30	2.99	2.05	2.35	2.33
excess air level, %	57	48	43	49	52
Secondary Combustion Chamber					
outlet gas temperature, °F	2,178	2,190	2,187	2,196	2,172
pressure, in. H_2O vacuum	0.8	0.4	0.7	0.8	0.7
combustion air flow, scfm*	857	717	758	932	1,041
diesel fuel flow, lb/hr	211	178	202	238	251
gas residence time, sec	2.56	3.18	2.49	2.55	2.35
oxygen, vol. %	7.70	6.97	6.44	6.42	7.55
carbon dioxide, vol. %	10.9	11.3	11.4	11.1	11.0
carbon monoxide, vol. ppm	4.1	2.0	2.3	2.5	3.5
Quench System					
process liquor pH	8.7	8.9	8.6	8.3	8.0
quench recycle flow, gal/min	45	46	41	50	54
makeup water flow, gal/min	12	7	9	9	12
CHEAF					
process liquor pH	8.6	9	9.8	9.1	8.8
CHEAF recycle flow, gal/min	17	9	13	13	15
pressure differential, in. H_2O	19	13	15	16	16
MX Scrubber					
process liquor pH	8.7	8.5	8.6	8.7	8.6
MX recycle flow, gal/min	127	171	163	161	145
Stack					
temperature, °F	164	168	179	171	173
pressure, in. H_2O	+0.62	+0.59	+0.59	+0.59	+0.54
gas flow rate, dscfm	3,649	2,876	3,167	3,299	3,361

*Combustion gas retention time and excess air levels calculated by material balance.

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TABLE 5. TCDD AND PARTICULATE MATTER EMISSION SUMMARY

Parameter	Permit Limit	Test 2				Test 3 Combined
		Run #2	Run #3	Run #4	Run #5	
Waste Feed Characteristics						
liquid waste feed						
total flow, lb/hr		233	236	234	247	
2,3,7,8-TCDD conc., ppm	400	249	357	264	225	
2,3,7,8-TCDD feed rate, g/hr	27.2	26.3	38.3	28.0	25.2	
solid waste feed						
total flow, lb/hr	2,000	1,158	1,363	2,068	1,322	973
2,3,7,8-TCDD conc., ppb		101	382	1010	770	
2,3,7,8-TCDD feed rate, g/hr		0.05	0.24	0.95	0.46	
Performance Standards - Stack						
DRE for 2,3,7,8-TCDD						
emission rate, mg/day		0.169	0.127	0.031	0.064	
DRE, %	99.9999	99.99997	99.99998	99.99999	99.99998	
bromine emissions						
emission rate, kg/hr						0.12
removal efficiency, %						99.0
particulate matter						
emission rate, mg/Nm^3 @ 7% O_2	180	134.3	147.3	145.6	201.5	

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TABLE 6. RESULTS OF MISSOURI TRIAL BURN

Parameter	Permit Limit	Test Number 2-2[a]	2-3	2-4	2-5	3-1,2,3[b]
Kiln						
temp., °C/°F	1400/1900	900	870	910	940	860
SCC						
temp., °C/°F	2050/2400	1190	1200	1200	1200	1190
O_2, vol. %	4	7.7	7.0	6.4	6.4	7.6
CO, vol. ppm	100	4.1	2.0	2.3	2.5	3.5
retention time, sec		2.5	3.2	2.5	2.6	NC
HCl removal efficiency, %	99	NA	NA	NA	NA	99.0
DRE, %						
2,3,7,8-TCDD[c]	99.9999	99.99997	99.99998	99.99999	99.99998	
Particulate emission rate, mg/Nm^3 @ 7% O_2	180	134	147	146	202	

[a] Test 2 liquid feed - TCDD-contaminated trichlorophenol still bottoms
solid feed - TCDD/trichlorophenol-contaminated soil

[b] Test 3 liquid feed - fuel oil
solid feed - TCDD and brominated naphthalene-contaminated lagoon sludge

combined results for three 0.5 hour runs

[c] 2,3,7,8-TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin

NC - not calculated

NA - not analyzed

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control train. (A 50 um cartridge filter was installed on the water recycle system for the mass transfer scrubber, and subsequent particulate testing was conducted in the stack during the field demonstration with results well below the RCRA particulate limits.) The CO emission values were equivalent to those from the best available incineration technologies and were indicative of very complete combustion.

The results of Test 3 were also satisfactory in that no bromine or chlorine was detected in the stack gas.

FIELD DEMONSTRATION

A number of activities remain to be completed as of this writing (January, 1986), including the field demonstration and Test 1 of the trial burn.

The objective of the field demonstration is to determine the rates at which various types of dioxin-contaminated liquids and solids can be fed into the system and decontaminated. In addition to evaluating the capability of the Mobile Incineration System, the demonstration will result in the cleanup of the majority of dioxin-contaminated material in southwestern Missouri. The specific materials to be incinerated are shown in Table 7, which includes the quantity and estimated dioxin concentration for each material. As of January 10, 1986, more than 1,700,000 pounds of solids and 140,000 pounds of liquids have been incinerated.

FINAL REPORTS

The final report will evaluate the economic, technical, and institutional viability of mobile incineration, and will include a feasibility analysis of a larger, "transportable" incinerator. Preliminary analyses are presented here based on results to date.

Economic Factors

The economics of on-site cleanup are complex and do not lend themselves to simple cost estimating approaches. The concept of a mobile incineration system comes with inherent constraints that must be observed during the design, engineering, and operation of the system. In order to be mobile, maximum size and weight limitations are imposed on the equipment design. Thus, the MIS is denied the "economies of scale," in that an equivalent crew size could be used to operate a stationary (or transportable) system that has a much larger throughput. On the other hand, one crew could potentially operate two or more mobile units on the same site. Since labor is a substantial portion of the operating cost, increasing the capacity (by increasing either the size or the number of systems, or by modifications to the design) significantly reduces the unit cost of waste material destroyed.

Other factors that affect the economics of the system are: (1) heat and moisture content of the material being processed, (2) the operating factor, or percentage of time that the system is able to process material once it has been set up, checked out, and put on stream, and (3) setup costs and the duration of a given operation.

A detailed procedure for estimating the unit costs of a mobile incinerator or any other complex on-site treatment system will be presented as part of the final report. This procedure can then be used to compare candidate technologies for Superfund use, thus assuring that all key elements are included in the comparative estimates.

Technical Factors

Design and operating decisions can significantly affect reliability, operating factors and, therefore, costs. The shakedown for the trial burn in Missouri, as noted above, was conducted during January through March, 1985. These experiences indicate that careful planning, conservative designs, a full complement of spare parts, and adequate redundancy are necessary for successful field operations.

As a temporary facility, the MIS installation did not incorporate many features found in a permanent facility, such as a high-quality access road or

TABLE 7. MATERIAL TO BE INCINERATED DURING FIELD DEMONSTRATION

Material	Estimated Quantity	2,3,7,8-TCDD Conc.
Denney Farm		
MDB soil	210 cu yd[a]	500 ppb
mixed solvents and water	2590 gal	Low
chemical solids and soils	31,150 lb	1 ppb - 2 ppm
drum remnants and trash	84 85-gal overpack drums	Unknown
Verona		
hexane/isopropanol	10,000 gal	0.2 ppm
methanol	5,000 gal	ppt
extracted still bottoms	5,000 gal	0.2 ppm
activated carbon	5,000 lb	Unknown
decontamination solvents	1,000 gal	Unknown
sodium sulfate salt cake[b]	23 cu yd	1 ppb
miscellaneous trash	84 55-gal drums	Unknown
Neosho		
spill area soil	282 cu yd	60 ppb
bunker soil/residue	15 drums	2 ppm
tank asphaltic material	75 gal	2 ppm
Erwin Farm		
contaminated soil	1264 drums	8 ppb
loose soil	160,000 lb	8 ppb
contaminated liquid	18 drums	Unknown
contaminated trash	16 drums	Unknown
Rusha Farm		
spill area soil	31.5 cu yd	Unknown
contaminated liquid	1 drum	Unknown
contaminated trash	2 drums	Unknown
Talley Farm		
spill area soil	176.5 cu yd	6 ppb
contaminated liquid	6 drums	Unknown
contaminated trash	16 drums	Unknown
Eastern Missouri		
Times Beach soil sample	3 cu yd	500 ppb
Piazza Road soil sample	3 cu yd	1600 ppb

[a] 1 cu yd = 1 ton (2000 lb)
[b] Will not be incinerated.

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electric line power. Lack of such features retarded progress during adverse weather conditions. Each site will have its own unique conditions that must be accommodated to reduce system downtime. The cost for specific site and equipment improvements must be weighed against system downtime costs. This trade-off also applies to the number of spare parts and the quantity of backup or standby equipment that is available.

In general, however, the technology elements for on-site cleanup by incineration are currently available and in common industrial use. There are no exotic or high technology elements in the MIS. The results of the field demonstration will include suggestions or design improvements that could be made by future, private sector incinerator owners.

Comparison with the Transportable Incinerator

Although the EPA Mobile Incineration System has clearly demonstrated the ability to destroy liquid and solid hazardous and toxic organic wastes, its relatively low capacity severely limits its use for the massive task of cleaning up the myriad abandoned hazardous waste sites already discovered. Since the capacity of a single mobile incineration system cannot be significantly increased without the loss of mobility, development of a modular, transportable incineration system appears to be a logical alternative for increasing capacity. Such a system would be transported to a site, assembled and operated on-site, and then dismantled and transported to another site. Accordingly, a project was undertaken in 1984 to examine the technical, administrative, and economic feasibility of the use of modular, transportable incineration systems for the destruction of toxic organic wastes at Superfund sites in the US. The operating premise of such a system is that it will:

- have a capacity of 5-10 times that of the EPA Mobile Incineration System
- be operated on a very large Superfund site for 1-3 years
- be constructed from currently available system components.

A rotary kiln with a secondary combustion chamber appears to be the most suitable type of incineration equipment for handling the broad spectrum of hazardous materials at Superfund sites. A 75 MM Btu/hr system is presently estimated to be the largest incineration system that could be transported without extensive field fabrication.

Two key variables that affect the system economics are primary and secondary combustion chamber temperatures and the types of wastes. A higher temperature operation requires more auxiliary fuel than a lower temperature, especially when only low fuel-value waste is available as would be the case at most Superfund sites. Therefore, if PCBs or dioxins are not present or are handled separately, significant operating economies could ensue by operating at lower temperatures.

The estimated cost for incinerating waste materials with a modular transportable system ranges from $52/ton for contaminated soil at the lower set of temperature conditions up to $561/ton for industrial solid wastes at the set of high-temperature conditions. These estimates include capital and operating costs. Waste excavation, transportation, and other non-direct costs are not included.

FUTURE USE OF THE MIS

Further use of the EPA Mobile Incineration System, after the field demonstration at Denney Farm, will be at the direction of the EPA Office of Solid Waste and Emergency Response.

The intention of future operations with the MIS is more to encourage commercialization of on-site cleanup technologies than it is to use the system consistently for cleanup activities. As a result of EPA experiences and operating information, the private sector will likely build improved, more reliable, larger capacity, lower cost systems of at least equivalent performance for use in routine cleanup operations.

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