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DISPOSAL OF WASTE OR EXCESS HIGH EXPLOSIVES

MASON & HANGER - SILAS MASON CO., INC.

PANTEX ERDA PLANT

DEVELOPMENT DIVISION

FINAL REPORT

JANUARY 1977

For

U.S. Energy Research and Development Administration

Albuquerque Operations Office

Albuquerque, New Mexico

MASTER

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Pantex Plant

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TABLE OF CONTENTS

ABSTRACT

The "Disposal of Waste or Excess High Explosives" project began January 1971. Various methods of disposal were investigated with the conclusion that incineration, at major ERDA facilities, would be the most feasible and safest method with the least cost and development time required.

Two independent incinerator concepts were investigated: a rotary type for continuous processing and an enclosed pit type for batch processing. Both concepts are feasible; however, it is recommended that further investigations would be required to render them acceptable. It is felt that a larger effort would be required in the case of the rotary incinerator.

The project was terminated (December 1976) prior to completion as a result of a grant of authority by the Texas Air Control Board allowing the ERDA Pantex Plant to continue indefinitely outdoor burning of explosives.

1.0 INTRODUCTION

The National Environmental Policy Act of 1969 and Executive Orders 11507 and 11514 directed all governmental departments to conform to established air and water quality standards and, in addition, to use all practical means, consistent with essential procedures, to improve those operations which may degrade the environment.

Resulting from these directives and others that followed, a project was conceived and organized by the Mason & Hanger - Silas Mason Co., Inc., under the guidance of the ERDA high explosives (HE) Facilities Master Plan Committee. The objectives of this effort were (1) to determine the magnitude of the problem associated with meeting the new regulations at the ERDA facilities and (2) to determine methods of disposal and develop a pilot-scale process for disposal of the waste HE.

On January 6, 1971, the following items were recommended by the Master Plan Committee:

1. A study of the procedures employed at each ERDA contractor facility for the disposal of high explosives and high explosives contaminated waste. This should include types and quantity of typical waste materials projected if possible to the next 10 years.

2. An evaluation of existing or proposed sampling and analytical techniques designed to obtain a quantitative estimate of the combustion products.

3. An estimate of the types and quantities of explosives and explosive devices expended by detonation.

4. A qualitative evaluation of alternate methods of disposal within the ERDA complex.

5. Development of any other sources which can contribute to the resolution of this problem.

The project continued for approximately 5-1/2-years, until on July 9, 1976, the Texas Air Control Board issued a written grant of authority for the ERDA Pantex Plant to conduct outdoor burning of explosive waste for an indefinite period of time. As a result it was decided to terminate the project (December 31, 1976), prior to its completion. In the ensuing years a great amount of information has been gathered on many subjects and due to an early termination of the effort, some further development effort would be required prior to the design of construction of a closed-pit incinerator facility.

This final report presents the results of the 6-year effort. For further details the reader is encouraged to consult the individual progress reports listed in Section 5.0.

The conclusions reached in the examination of the various possible methods to dispose of waste explosives are given. Based on these conclusions incineration was chosen as the best known method of disposal. Incineration was then examined in detail with the operation of two different incinerators—a rotary type and closed-pit type.

2.0 REVIEW OF DISPOSAL METHODS

Because of the differences in molecular structure and physical properties of the many available types of explosive compounds and mixtures, a potential method of disposal for one type of material may not be suitable for another material. For example, the initiating explosives such as lead azide and mercury fulminate need to be classified and handled separately—for safety, if nothing else—from less sensitive compounds such as TNT, HMX, RDX, PETN and HNAB. Also, plastic bonded explosives and mixtures represent another category.

Because of the variations in the molecular structure of various HE compounds potential chemical or biological decomposition of the explosive may be directly related to the structural configuration. An aromatic carbon ring structure as present in TNT and picric acid consists of strong carbon bonds and is much more difficult to decompose than a non-aromatic ring structure as in RDX and HMX where some nitrogen-carbon bonds are present. PETN represents another type (linear) structure. Since ERDA applications require diminishing amounts of TNT and RDX and increasing amounts of HMX and PETN the ERDA disposal problem may differ radically from the DoD. Therefore, the DoD requirements for disposal methods will not necessarily be the same as for the ERDA facilities.

The potential methods for HE disposal under consideration are presented in Fig. 1. The materials are divided into three groups: (1) sensitive (lead azide, etc.), (2) waste and surplus explosives during manufacture, and (3) obsolete weapon system explosive (considered separately because of potential security classification problems). The methods of disposal are also divided into two groups for dispersion: (1) at each facility or (2) at central sites. Further discussion of the individual methods of disposal follows under the respective sub-headings.

2.1 OPEN BURNING

DESCRIPTION: *HE and HE-contaminated waste are collected and transported to the burn site where they are placed on impermeable tar or asbestos sheets, ignited by squibs, and burned in the open, ambient air. A mesh cubicle is used for the contaminated waste paper to contain the burning scraps of paper.*

ADVANTAGES: 1. *This method is reasonably safe, if carried out correctly, since handling and transportation are minimized and remote operation is used because there is a small probability of accidental detonation on the pad during burning.*

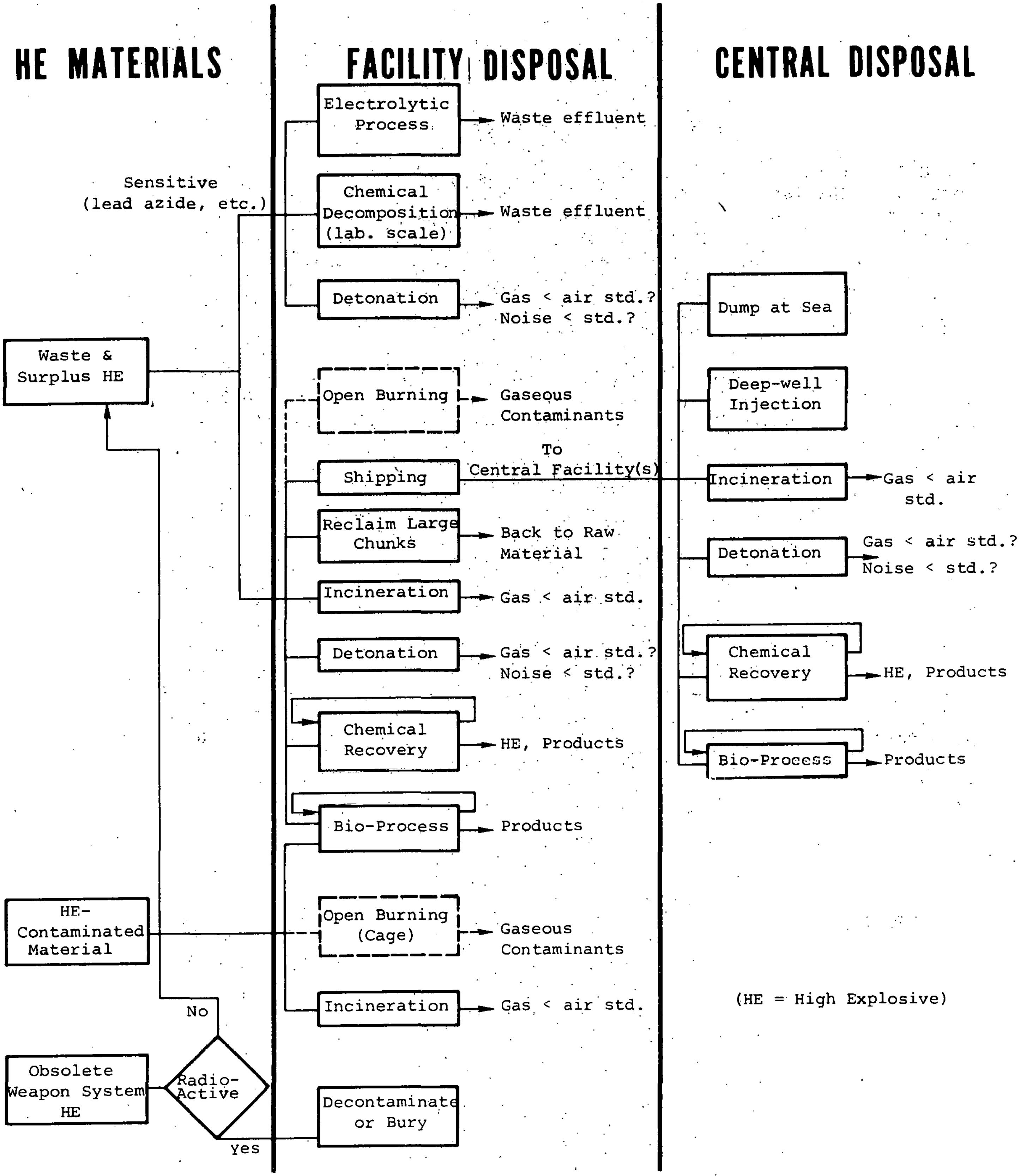

Fig. 1. Potential Methods for HE Disposal

2. *This method is economical since few people are required for transportation and burning. Facilities investments and maintenance costs are also low, involving a burn area, a mesh cubicle, wiring provisions for ignition and a small control building.*

DISADVANTAGES: 1. *While not necessarily applicable to Federal facilities, open burning has been banned in most regions, with some exceptions for the disposal of waste materials for which other disposal methods are not at hand.*

2. *Some potential for exceeding the ambient air pollutant standards exists.*

3. *No potential for recovery or recycle of products (loss of natural resources).*

2.2 DETONATION

DESCRIPTION: *HE and contaminated materials are collected and transported to the detonation area. Layout is similar to burning except that detonators, and some containers for explosives may be required. A concrete and steel bunker is used for protection of the detonation crew when working close, as in diagnostic test firing.*

ADVANTAGES: 1. *This method is reasonably safe because handling and transportation are minimized.*

2. *Detonation is economical since manpower and facilities are similar to those required for burning. However, some retaining structure may be required to curtail noise and ground shock.*

DISADVANTAGES: 1. *As stated previously, open burning has been banned in many regions and detonation might be considered as burning.*

2. *Noise levels may be high.*

3. *Potential for shock damage and nuisance suits.*

4. *No potential for recovery or recycle of products (loss of natural resources).*

2.3 INCINERATION

DESCRIPTION: *Many types of incinerators are in use and new designs are being developed. The double-chamber incinerator with air recycle and exhaust devices is particularly efficient for decreasing pollution and is used extensively in Europe. Pollution control units can be added to the exhaust stack to control the emission levels at the required standards or lower. The double-chamber allows a lower burning temperature which reduces the formation of* NO_x*. The air recycle helps keep the burning temperature low and insures combustion of residue gases in the air. Burning with gaseous fuel at a slightly rich fuel/air ratio tends to decrease the formation of* NO_x*.*

Another incinerator concept features an open pit. This pit concept is particularly attractive for HE and contaminated material disposal because of the large opening for safe loading and the sunken pit for contamination in case of accidental detonation. The HE material can be dumped directly into the trench and then, if desired or needed, a housing-on-rails can be moved into position over the pit to control emissions to lower levels. Also, gas jets can be added for igniting the material.

COMMENTS: *Significant progress has been made within the EPA in developing double-chamber incinerators for municipal refuse. These units are quite sophisticated to efficiently dispose of a variety of refuse materials including plastics and potent toxic pollutants, e.g., household medicines and insecticides.*

ADVANTAGES:

1. *Meets regional requirements banning open burning.*
2. *Allows control of air pollutants (not possible with open burning).*

DISADVANTAGES:

1. *High initial and operating costs.*
2. *Less safe and reliable since an accidental detonation could damage the unit or even injure people (if not properly designed at added expense). Also, added potential hazards exist when loading HE and contaminated material into the incinerator (must be shut down and cooled between burns).*
3. *No potential for recovery or recycle of product (loss of natural resources).*
4. *Added development effort required for reliable operation to meet emission standards.*

2.4 DEEP-WELL INJECTION

DESCRIPTION: *The well must be located in an area where a sandstone bed, cavern or other permeable layer is available for injection. Also, strata between the injection zone and ground water supplies must be impermeable to prevent ground water contamination. Wells are usually pressurized to about 185 psi and the average depth is 2700 feet. Many areas of the U.S. are available as potential sites. Texas, Ohio, Missouri and California have statutes to regulate wells. Texas, in particular, has 20,000 brine injection wells.*

The use of solid HE materials would require the development of slurries for injection. In addition, the injection zone would need to consist of a cavern or extremely porous structure in order to prevent clogging of flow passages with particulate matter.

ADVANTAGES:

1. *No air pollutants are generated.*

DISADVANTAGES:

1. *Transportation may be required to ship waste materials to areas where acceptable sites are located. Transportation requires storage facilities, railroad cars, added manpower and involves additional danger of explosion during transit and storage.*
2. *Potential ground water contamination if the well liner cracks or from seepage.*
3. *Added costs for processing the HE to form slurries.*
4. *Added danger from potential hazards during the slurry processing.*

2.5 OCEAN DUMPING

DESCRIPTION: *The material to be dumped is transported to a coastal area and is then loaded on barges and dumped at sea, or alternatively, is piped some distance at sea. The site for the dump must be chosen to avoid injury to commercial or ecologically important fish, shrimp, and other marine life. The dispersion of the materials is estimated in a similar manner to stack gas dispersion methods with diffusion and convection in ocean currents included. The loose HE and HE-contaminated materials such as cloth and tissues should decompose readily in the ocean environment because of the algae and bacteria.*

Costs for dumping at sea depend on the availability of seacoast facilities and barges. Annual costs for rail transportation and barges excluding facilities and manpower costs might be prohibitive. Another possibility for ocean dumping is the use of tectonic sinks (zones where the earth's surface is being drawn into the mantle). The waste material would then be recycled into the earth. A third would be detonation out in the ocean, either on the surface or after sinking, to reduce possible risk of later explosion.

ADVANTAGES:

1. *No pollution products are generated.*
2. *Potentially, complete decomposition is possible.*

DISADVANTAGES:

1. *Ocean dumping is politically unpopular at present as a "pollution" per se.*
2. *Hazards exist during rail and barge transportation.*
3. *Costs of transportation and storage facilities are higher than incinerator costs.*

2.6 BIOCHEMICAL DECOMPOSITION

DESCRIPTION: *The ingredients in the present HE are ideal as a diet for bacteria since the organic material required for a food source and the nitrogen as required for the bacterial environment are both present. However, the rate of decomposition will depend greatly on the structure of the HE, the types and amounts of binders, and the strains of bacteria used. Some time will be required to locate and develop a strain of bacteria and to optimize the strain and the required environmental conditions such as temperature, pH, and supplementary nutrients. The end products from the microbiological process may have agricultural and industrial uses.*

ADVANTAGES:

1. *Recovery of HE materials as saleable chemicals may be possible.*
2. *Recovery rate may be faster with less chemical residue than chemical recovery methods.*
3. *Even the HE-contaminated materials may be included in some processes with a decrease in potential water and air pollution.*

DISADVANTAGES: 1. *No biosystem has been developed; feasibility studies are needed.*

2. *Development time may be significant.*

3. *Facility and manpower costs for a complex system might be higher than for an incinerator but may be competitive with chemical recovery methods.*

4. *Different types of HE may require separation to achieve optimum recovery.*

2.7 CHEMICAL RECOVERY

DESCRIPTION: *Chemical recovery methods have been investigated and tested at the laboratory level. These methods include recovery from mixtures as well as from segregated explosives.*

COMMENTS: *Chemical methods are in use for dissolving and decomposing small batches of a sensitive detonator explosive (lead azide). In general, chemical processes require the use of solvent before further treatment. The subsequent recovery of the solvent and other chemicals is a major factor in developing an acceptable chemical recovery/recycle process. (If the solvents and chemicals are not recovered they may cause more pollution than the original HE.) Chemical recovery is not presently practical for HE-contaminated waste materials.*

ADVANTAGES: 1. *Potentially high recovery of HE materials.*

2. *Processes verified by laboratory experiments.*

3. *Has acceptance and present use in decomposition of a sensitive detonator explosive.*

DISADVANTAGES: 1. *Facility, manpower, and supply costs will be higher than for an incinerator system.*

2. *Potential pollution problems with spent solvents and treatment chemicals. (Recovery of solvents for reuse is virtually mandatory to make processes acceptable with respect to cost and pollution.)*

3. *Development required since recovery processes are not currently in use for most explosives.*

4. *Not useable for HE-contaminated waste materials.*

The study of methods of disposal of explosives led to the conclusion that incineration at major ERDA facilities is presently the most feasible and safest method available with the least cost and development time required. Therefore, the remainder of the effort was concentrated on the development problems relating to incineration of explosives and the accompanying problems of pollution abatement.

3.0 PROTOTYPE INCINERATOR DEVELOPMENT

An incinerator-complex was designed to take care of the HE disposal needs at Pantex. It was designed to process as much as 250,000 kg (one-half million pounds) of HE and HE-contaminated material per year. The waste material consists of a variety of sizes, shapes and types of explosives. Fig. 2 shows the proposed waste disposal facilities site plan. A typical list of burn products is given in Table I.

To supply the necessary design data two incinerators were investigated: a rotary-type and a closed-pit type. The incinerators were acquired and operated.

3.1 ROTARY TYPE

Fig. 3 is a layout drawing of the rotary incinerator. Fig. 4 is the overall view of the facility. The incinerator itself is shown in Fig. 5 and a view of the control room is shown in Fig. 6. The rotary incinerator effort was conducted at the ERDA Burlington, Iowa Plant and was completed in 1975.

The incinerator is a rotary kiln manufactured by Bartlett-Snow. It has a tube length of 172.7 centimeter (cm) with an inside diameter of 16.5 cm. Rotation is by means of a variable speed drive providing a speed range of 0 - 9.8 rpm. The inside of the tube is provided with six uniformly spaced vanes 2.5 cm deep. Heat is provided by fourteen propane burners uniformly spaced along the tube.

Material is fed into the incinerator from a hopper by means of a screw which displaces 95.8 cm^3 of material per revolution. The screw feed is also provided with a variable drive. Combustion air is provided by an electro-type draft inducer. Air flow is controlled by means of a butterfly valve combined with a 5 cm bleed valve placed between the butterfly and the draft inducer.

Thermocouples are provided to monitor the hopper temperature, exhaust gas temperature and the temperature of the outer tube at four points. A single thermocouple monitors the temperature inside the tube at a point approximately 46 cm from the discharge end. These temperature sensors are read on strip chart recorders.

Effluent gases are monitored by means of an Aerochem Chemiluminescent NO_x monitor and a Beckman DIF 7000 Carbon Monoxide Analyzer. The sample gas is drawn through a 1.3 cm stainless steel tube tapped into the exhaust line upstream of the draft inducer. A "Fireye" smoke detector is installed in the exhaust stack downstream from the draft inducer to provide some information on the level of particulate emission. This instrument has a dual scale output reading in Ringleman numbers and percent optical transmission.

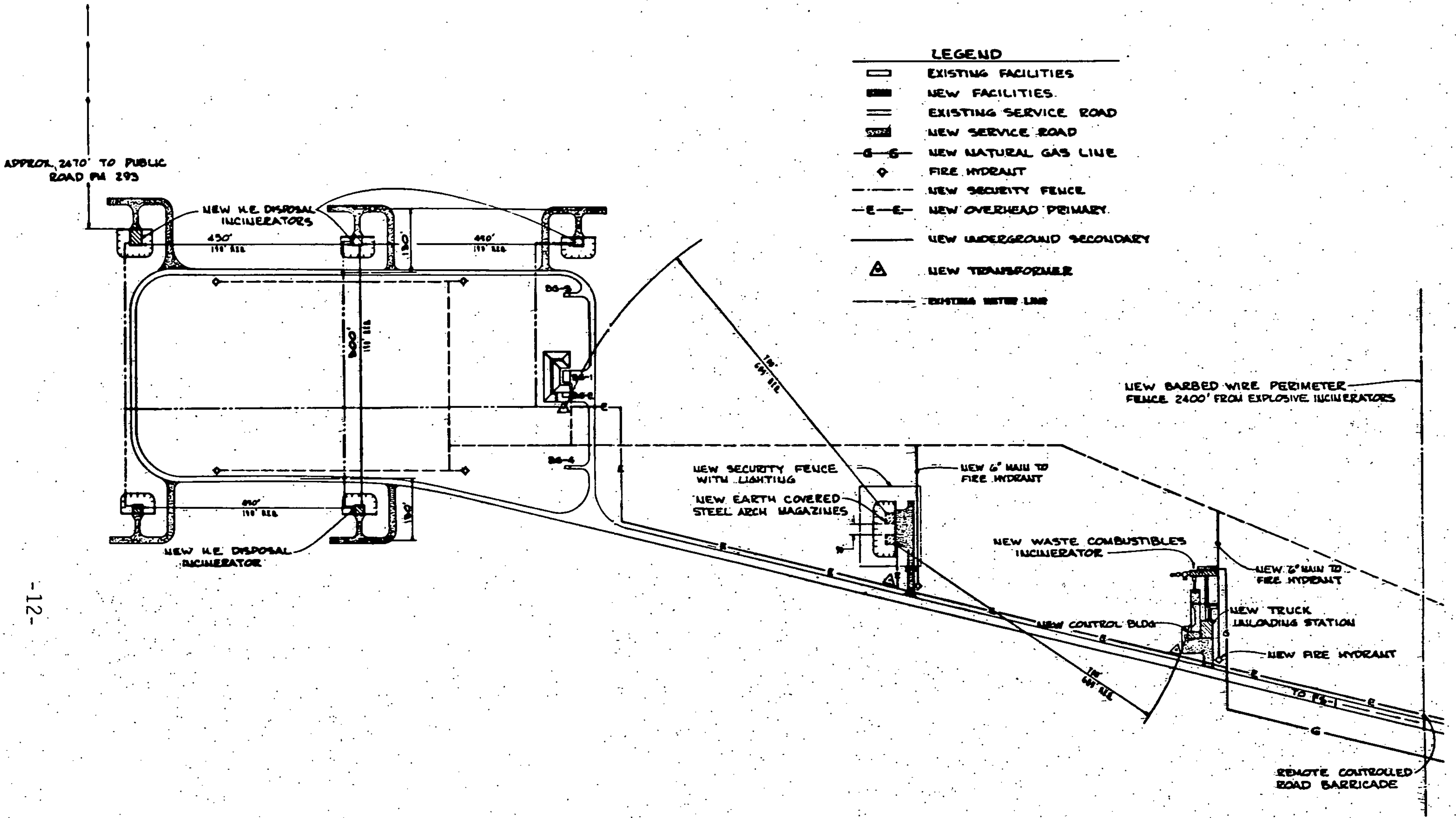

Fig. 2. Proposed Waste Disposal Facilities Site Plan

Table I. Combustion Products for PBX-9404

Gas	Yield (mℓ/g)	Mol. Wt.	Moles/g	Wt./g
N_2	253.00	28	0.01012	0.28336
O_2	-166.00	32	-0.00664	-0.21248
CO_2	300.00	44	0.012	0.528
H_2O	230.00	18	0.0042	0.1656
N_2O		44		
CO	2.20	28	0.000088	0.002464
NO_x	9.20	30	0.000368	0.01104
H_2	0.12	2	0.0000048	0.0000096
Ash	2.45 (wt. %)			0.0295

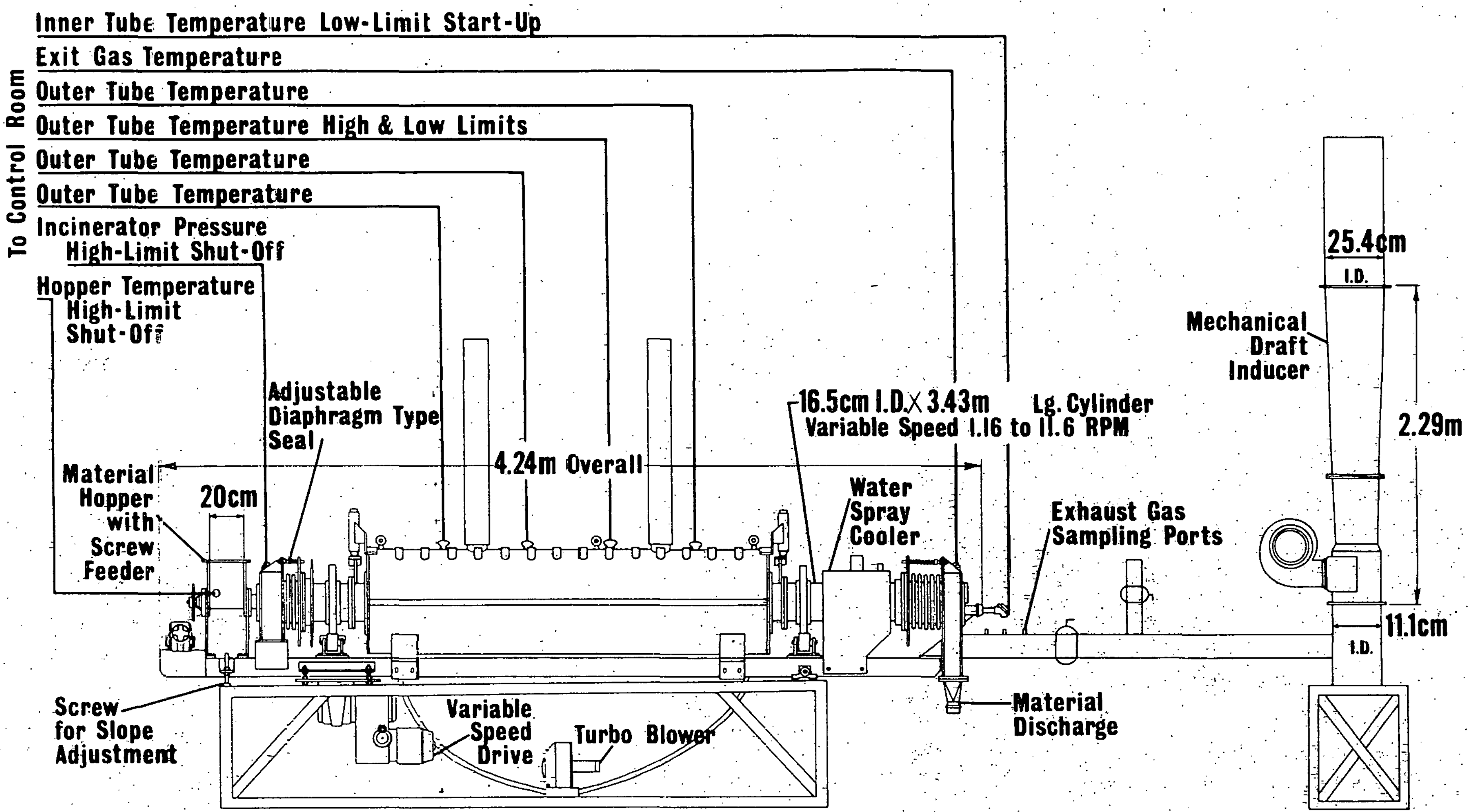

FIG. 3 INDIRECT-FIRED ROTARY INCINERATOR

Fig. 4. General View of Pilot Incinerator Facility

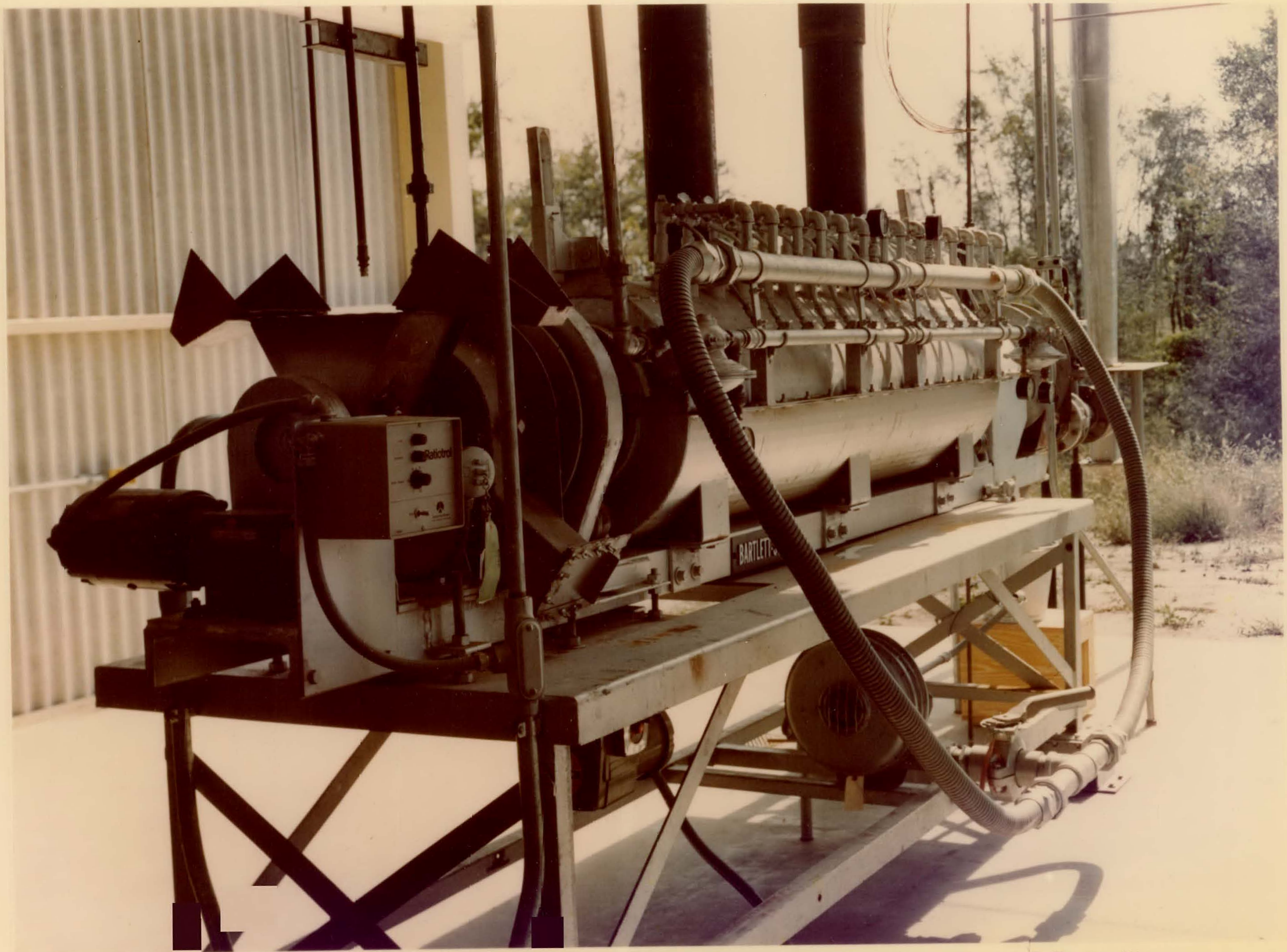

Fig. 5. View of Incinerator from Feed End Showing Hopper, Burner Arrangement & Turbo-Blower

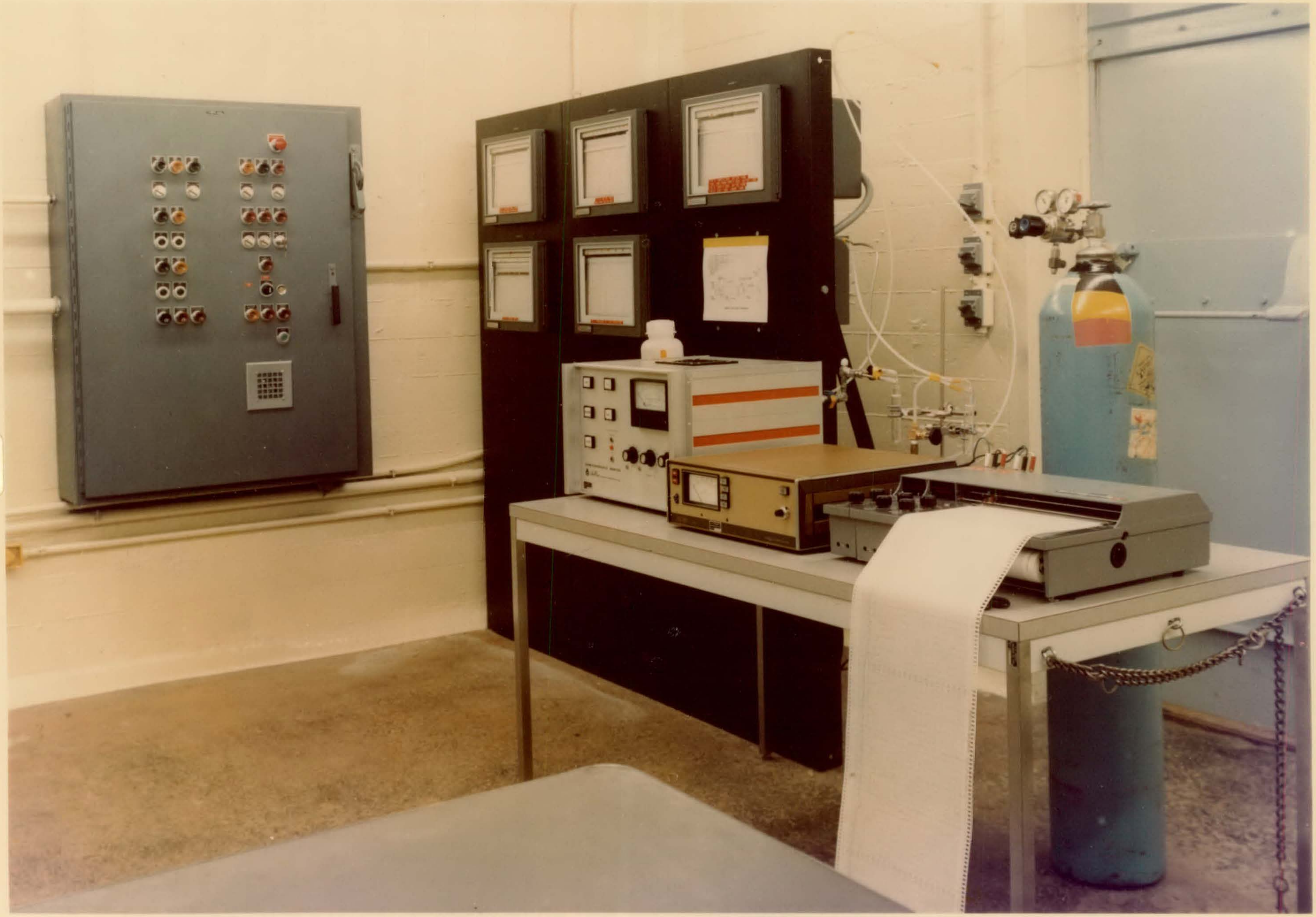

Fig. 6. Interior View of Incinerator Control Room

Following an initial shakedown and debugging period, a series of experiments were conducted starting with paper followed by contaminated combustible trash, and then HE with several inorganic diluents. The HE burned was, in all cases, PBX 9404. The diluents employed in varying concentrations were sand, fly ash, crushed limestone and 0.3 cm alumina balls. The mixtures were moistened to inhibit any tendency for the combustion to train back up the tube and ignite the charge in the hopper. Only one or two burners were used, creating an ignition zone which appeared to be 25 to 35 cm long.

It was quickly learned that crushed limestone was the best material for this purpose. Sand and fly ash, when moist, tended to cohere and bridge over the feed screw. A vibrator installed on the hopper was not much help. The alumina balls traveled down the incinerator tube at a much higher rate than the grains of PBX 9404 and consequently were not as effective as a diluent.

The traces from the CO and NO_x monitors showed great fluctuations in the concentration of combustion products. This suggested a very uneven rate of combustion, possibly due to a "bridge-over, fall in" type of feed in the hopper. This led to a decision to attempt dry burning. The first such burn was attempted with a limestone-HE charge containing approximately 20% HE by weight. The rate of tube rotation was increased by one-third, while the feed rate was diminished by the same factor compared to the values employed with moist material. Combustion appeared to be smoother. On a rerun, the rough combustion phenomenon reappeared. This unsteady combustion was present to at least some degree in a major portion of the burns. It is now believed that the material burned back up the tube a short distance from the ignition zone and the combustion died out as it moved into the cooler portion of the tube.

To assist in establishing the capabilities of the system it was decided to undertake a series of experiments in which PBX 9404 was burned without diluent. For these experiments the charge was limited to 0.23 kg. The feed rate was initially to be 20% of that employed in the previous experiments made with limestone diluent, thus feeding the high explosive in at approximately the same rate as in these experiments (the limestone mix was 20% HE).

It was anticipated that there would exist a critical feed rate at which the combustion would train back up the tube and consume its entire contents. By limiting the charge to 0.23 kg the hopper and screw feed would be empty by the time the explosive reached the combustion zone, which is located about 38 to 41 cm from the discharge end of the tube. In practice, this worked out as expected.

A total of thirteen burns were made with the straight PBX 9404, starting at a feed rate of approximately 0.23 kg per hour (kg/hr). Until the first flashback occurred, each burn was run at a feed rate approximately 50% greater than that of the previous one. The first flashback took place after the charge had been injected at a rate of 7.3 kg/hr. The rate was cut back to 4.1 kg/hr with no flashback, then increased again to 6.6 kg/hr without incident. Two runs at 9.5 and 9.3 kg/hr produced flashbacks, as did a final run at 6.9 kg/hr.

Further evidence that the combustion proceeded in bursts came from the record of the NO_x monitor and also, when the intensity was sufficiently high, from the records of the temperature at the combustion zone, the temperature of the exhaust gas and the record of the smoke monitor. The assertion that, at a critical rate of charge injection, the entire charge burned in a single massive flare is based on evidence from the records of all the instruments that were monitoring the process.

The feed rate figures quoted in this report are derived from the dimensions and rotation rate of the feed screw, which has a diameter of 5.08 cm and a lead of 5.5 cm with a shaft diameter of 1.59 cm. For the mixture of PBX 9404 and inert diluents, feed rates are quoted in cubic centimeters per minute. For straight PBX 9404 molding powder they are given in kilograms per hour, based on a bulk density of 0.88 gm/cm^3.

NO_x concentrations ran as high as 2500 ppm on the burns of pure PBX 9404. Only one CO record was obtained, covering the last five burns. This showed peak values of approximately 2.5%.

Emission of particulates was probably very low. "Smoke density" readings on the Fireye smoke detector tended to range between 10% and 20% when the explosive was burning slowly and quietly, and spikes up to 40% to 45% appearing during a flashback incident. There is reason to believe that much of what was detected was condensed water vapor, as these burns took place in October and November when outside temperatures were low. During the warming up of the tube the smoke density reading would rise from its initial zero value to as much as 60%, then fall gradually back to values in the 0% to 20% region. As nothing could be seen issuing from the stack, it is assumed that this was due to moisture vaporizing from the tube and condensing on the cold surfaces of the optical elements which were exposed to the stack gases. It is quite possible that when the hot stack gases, laden with moisture formed during the rapid combustion of a flashback mixed with a jet of cold air generated by the inductor blower, a cloud of condensed water droplets formed which the detector system interpreted as "smoke."

The data obtained from the burns with diluted PBX 9404 are listed in Table II, those from the straight material in Table III. The figures for NO_x emission are very erratic, although a rough correlation with feed rate can be seen.

The air flow through the system for all runs was that obtained with the lowest setting of the draft inducer and was roughly 5 cfm. This low setting was employed as a result of an experience during the early tests in which a dummy burn was carried out with 6.8 kg of dry sand, employing a relatively vigorous draft setting. More than 50% of the sand was entrained by the air stream and carried into the exhaust system.

Table II. HE With Inorganic Diluent

Burn No.	Charge Weight (lb)	Diluent	HE (%)	Wet or Dry	Feed Rate (in^3/min)	Initial Temperature (F)	Maximum NO_x (ppm)
1	2.25	Fly Ash	12.5	W	-	-	-
2	7.375	Alumina Balls	6.8	W	-	-	-
3	7.500	Sand	10.0	W	-	1330	125
4	6.690	Limestone	11.2	W	10.8	1370	-
5	7.440	Limestone	20.2	W	10.8	1280	440
6	7.440	Limestone	20.2	D	3.3	1270	1650
7	7.440	Limestone	20.2	D	3.3	1290	900
8	7.440	Limestone	20.2	D	3.3	1290	340

Table III. Straight HE

Burn No.	Feed Rate (lb/hr)	Initial Temperature (F)	Flashback	Maximum NO_x (ppm)
9	1.1	-	-	*
10	Power Failure	Data Lost		
11	1.1	1340	No	425
12	1.8	1330	No	*
13	2.7	1250	No	195
14	4.8	1290	No	1000
15	7.0	1350	No	925
16	10.0	1370	No	1125
17	15.9	1380	Yes	2500
18	9.1	1300	No	*
19	14.6	1310	No	*
20	21.0	1340	Yes	*
21	20.4	1370	Yes	*
22	15.3	1390	Yes	*

**NO_x Monitor Inoperative*

This investigation cannot be considered complete. An estimate of the capability of the system, in terms of safe consumption of dry PBX 9404 under the conditions of the tests conducted thus far, can be made (a conservative figure would be approximately 3.4 kg/hr); no statement could be made with respect to performance at higher rates of air flow. It seems reasonable to suppose that the flow of air, cooling the material and carrying hot gases toward the combustion zone is a counteragent against the tendency of combustion to train back up the tube from the point of initiation. The degree of this effect has not been determined.

Prior to being fed into the incinerator most explosive materials will have to be processed to a uniform particle size. For safety purposes water is normally employed for lubrication and cooling during this size reduction process. It is therefore anticipated that all material fed into a working incinerator system will be wet. This is desirable from a safety standpoint as it would suppress the tendency of the combustion to backtrain. Relatively little work has been done with wet material.

The system as it exists has several problem areas. The screw feed functions without difficulty when dry material is being fed, but becomes erratic with wet material due to the tendency of such material to bridge over the screw. It seems likely that a system using a belt or chain conveyor could be designed to give better performance.

The incinerator itself was not designed specifically for HE waste disposal. It has been described as a cement mill. It was, however, available off the shelf and served as a starting point for a study of this means of disposing of HE scrap.

In order to confine the combustion of the material to the heated zone, which should be some distance from the point where the feed enters the device, the material should be spread out as thinly and uniformly as possible over the inside of the tube. To achieve this the vanes should be as numerous and as shallow as practical. A study of the action of this system shows that, at best, the material can be distributed over an area on the ascending side of the tube which subtends from 90 to 120 degrees, the exact values depending on the angle of repose of the material.

A study of the performance of the present system with its six fairly deep vanes shows that the material tends to be carried on just two of the ascending vanes. In addition to this fundamental weakness, there is a structural problem. The vanes are not attached directly to the wall of the tube, but are welded to rings which are clamped in place. Two of the vanes fail to touch the tube wall, the clearance being approximately 0.32 cm. As these vanes ascend, at a point of 30 to 40 degrees up from their lowest position the bulk of their load trickles down through the clearance to be received from the following vane. As a result of this there are periods of some 75 to 90 degrees duration during which practically the entire load in the incinerator bares on a single vane, forming a powder train back to the input end.

The vane system can be improved by the use of shorter and more numerous vanes whose inner edges are maintained in contact with the wall of the incinerator tube. The system can be further improved by "rifling" the vanes. If the vanes are given a twist of only one turn between the input end and the combustion zone it becomes impossible for a continuous train of static material to exist.

A rotary incinerator can probably be designed which will safely consume explosives at a very high rate. The controlled burning of granulated secondary high explosive presents a very small probability of initiating a detonation. The rotation of the combustion tube tends to keep the material spread out in a thin, loosely packed layer, unsuitable for the propagation of a detonation.

The possibility that combustion will propagrate into the fuel supply exists with any burner, but there are special problems with explosives, because these materials can burn quite rapidly without any external oxygen supply. The rotary incinerator, if operated at a suitable feed rate, presents a situation unfavorable for train combustion by keeping the material in a thin, loose layer in contact with a good heat sink.

From the environmental standpoint, contained continuous combustion is an attractive way of disposing of excess HE because the products of combustion can be confined and treated to remove their noxious components by means of a suitable system of afterburners, scrubbers, filters, etc. The rotary incinerator project was terminated in April 1975.

3.2 CLOSED-PIT INCINERATOR

A batch-type closed-pit incinerator investigation was conducted at the ERDA Pantex Plant, Amarillo, Texas. A full-scale test (FST) facility was constructed and completed in July 1974.

The facility is, in essence, an enclosure in which large batches of explosives can be burned and is shown in Fig. 7 and 8. The purpose of the facility was to provide sufficient data for the design of the large incinerator complex for the Pantex Plant.

The closed-pit incinerator developmental program was divided into four phases. The definition of each phase is given below.

PHASE I — Determine feasibility of burning a large quantity of explosive in a closed pit-incinerator.

PHASE II — Establish basic design information for the incinerator structure, maximum number of burns per day and limitation of burn conditions.

Fig. 7. Full-Scale Test Facility

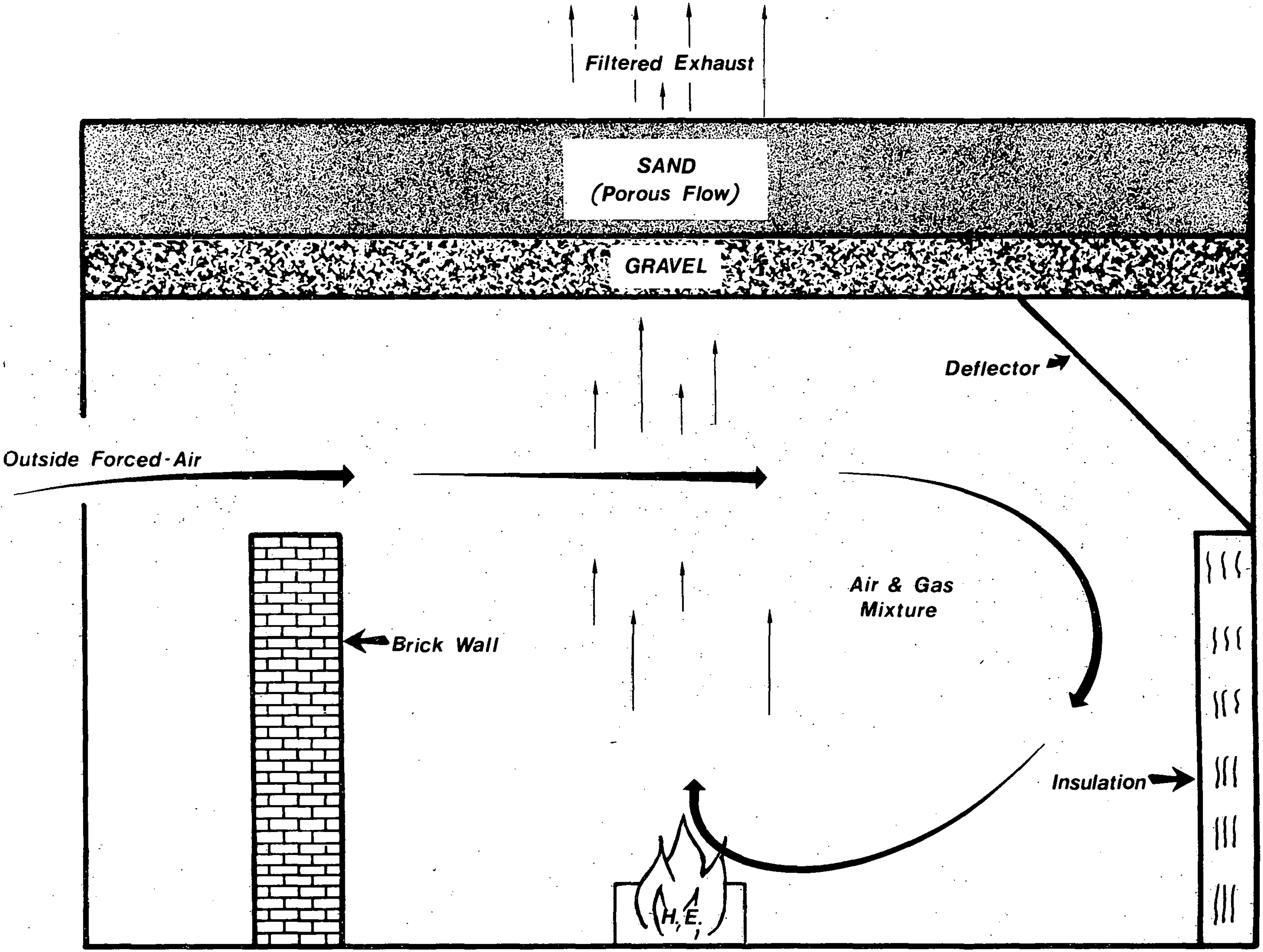

Fig. 8. Closed-Pit, Batch-Type Incinerator Concept

PHASE III Define pollution conditions and establish abatement requirements.

PHASE IV Develop burning procedures and safety requirements for the incinerator complex.

The project was terminated just prior to the completion of Phase III.

Phase I was completed by the end of 1974 with the conclusion that the FST design could repeatably process (burn) 454 kg of HE without detrimental effects.

Phase II was a study of temperature and pressure effects caused by large mass flow-rates developed during burning. The temperature and pressure also depends on the thickness of sand (Fig. 8) used in the overhead filter. Phase II was a systematic variation of both mass flow-rate of HE gases and thickness of sand. The important information gained were air temperatures, overhead I-Beam temperatures, air flow requirements, flame containment, wall temperature and I-Beam deflections.

Gas generation rates vary widely for the variety of explosive waste anticipated for the disposal program and may be categorized as follows: large billet type pieces exhibiting a low exposed surface area, e.g., 25 kg hemispheres; high-surface-area machine waste with varying moisture content; and a medium-area waste such as pressed HE pieces a few centimeters in size. It is expected that dry machine waste will generate high mass-flow-rates whereas damp machining waste will produce the lowest rate. The large billets and small pieces were expected to develop flow rates between these values.

When dry machine-waste was burned in the incinerator, dust was observed coming from the overhead filter. Since there is little dirt in the sand and gravel filter, the origin of the dust was probably the incinerator floor. Photographs of dry machine-waste burning in the open (at the burning grounds), show that sufficient winds are generated to create blowing dust in the vicinity of the pad. Dust was not observed coming from the incinerator when low-surface area billets were burned.

The temperature of the air inside the incinerator is plotted in Fig. 9. The range of values indicate the degree of uniformity throughout the incinerator. Slower burn rates produce more uniform air temperatures within the incinerator. Higher burn rates, for a given amount of explosive, produces higher air temperatures, and the larger the amount of explosive the higher the temperature.

No dependence was detected on filter (sand) thickness for the inside air temperature. This insensitivity to filter thickness is in agreement with predictions obtained from a calculated model of the incinerator. This model predicts that the rise in air temperature, ΔT_{∞}, for a constant burn rate is given by

$$\Delta T_{\infty} = \frac{\kappa}{\beta \, Cp}$$

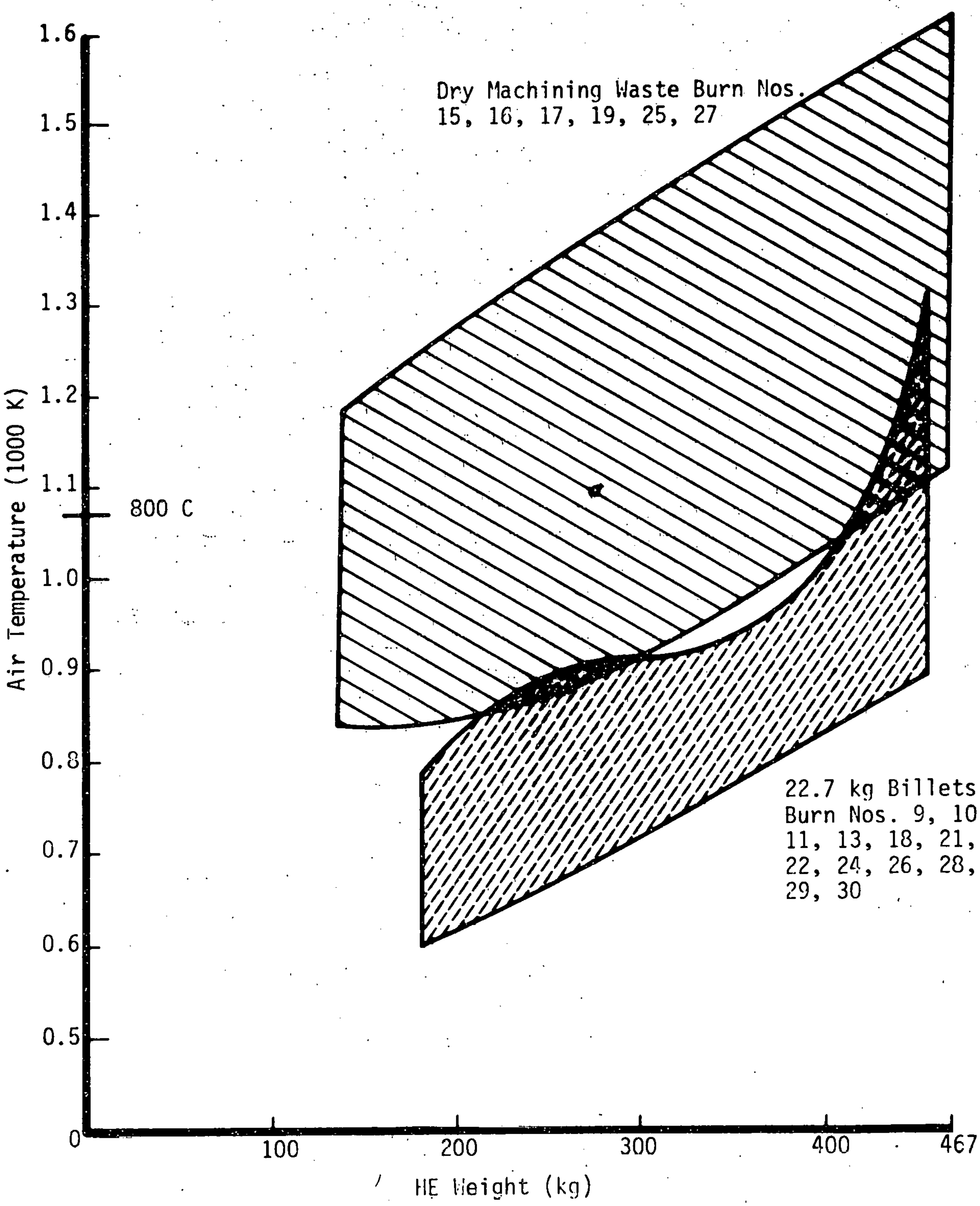

Fig. 9. Air Temperature in the Incinerator as a Function of HE Weight

where κ is the rate of energy release (cal/s), β is the outside air flow (g/s) and C is the average specific heat of the air and gases within the incinerator (cal/g C). If porous-flow is maintained through the filter an increase in thickness of the filter will only result in an increase in pressure inside the incinerator. The temperature will be unchanged if the flow through the filter is unchanged.

Heat radiation from the fireball is an important heat transfer mechanism within the incinerator. Radiation causes very high instantaneous surface temperatures on the walls and I-Beams. From Fig. 10 it can be seen that one-fourth to one-third of the temperature measured by a thermocouple may be due to heat radiation. Surface temperatures are likewise higher (Fig. 11), however, radiated heat is not penetrating radiation and can be very effectively reduced, if need be, by shielding. The temperature of the fireball is approximately 1900 K.

Maximum I-Beam temperatures are plotted in Fig. 12 for fast and medium-fast burns. The larger the amount of explosive burned the higher the I-Beam temperature and for a given amount of explosive the slower burns heat the I-Beams to a higher temperature. For these burn rates and for a capacity-burn (454 kg) or less the temperatures of the I-Beams were well below the maximum allowable temperature (810 K or 1000 F).

Fig. 13 is a graph of I-Beam temperature as a function of burn time, in which a fixed amount of HE is burned (454 kg). Even though there is considerable scatter in the data the graph indicates that a slightly longer burn, i.e., 4 or 5 minutes, may heat the I-Beams over 810 K. These data generated an interest in investigating "long burns" in the incinerator. "Long burns" have also been observed at the Pantex burning grounds. The project was terminated before this effect was studied.

With the aid of the blowers the I-Beams can be cooled to within 10 K of ambient temperature two hours after the burn. This makes it possible to reuse the incinerator several times in one work shift. Natural cooling of the I-Beams (blowers off) requires 22 hours. This is shown in Fig. 14.

A vertical deflection (sag) of the I-Beams at the center of the incinerator during a burn was measured, and a value as high as 3.5 cm was observed. The I-Beam temperatures were not severe and the deflections appeared to be elastic. "Long burn" effects were not evaluated with respect to I-Beam temperatures nor is it known what long-term effects are produced by large, repeated, elastic deflections.

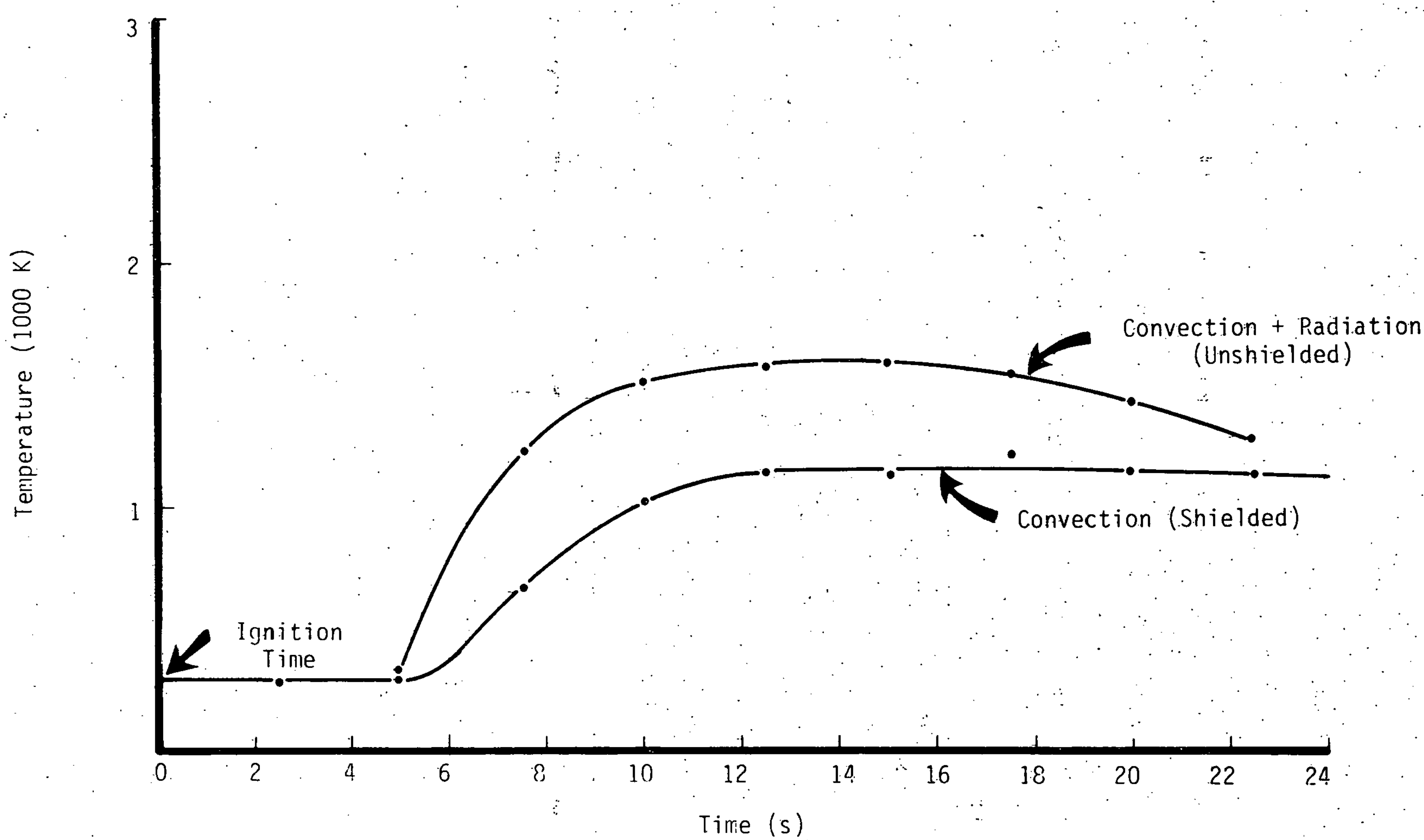

Fig. 10. Shielded and Unshielded Thermocouple Readings for Burn No. 19

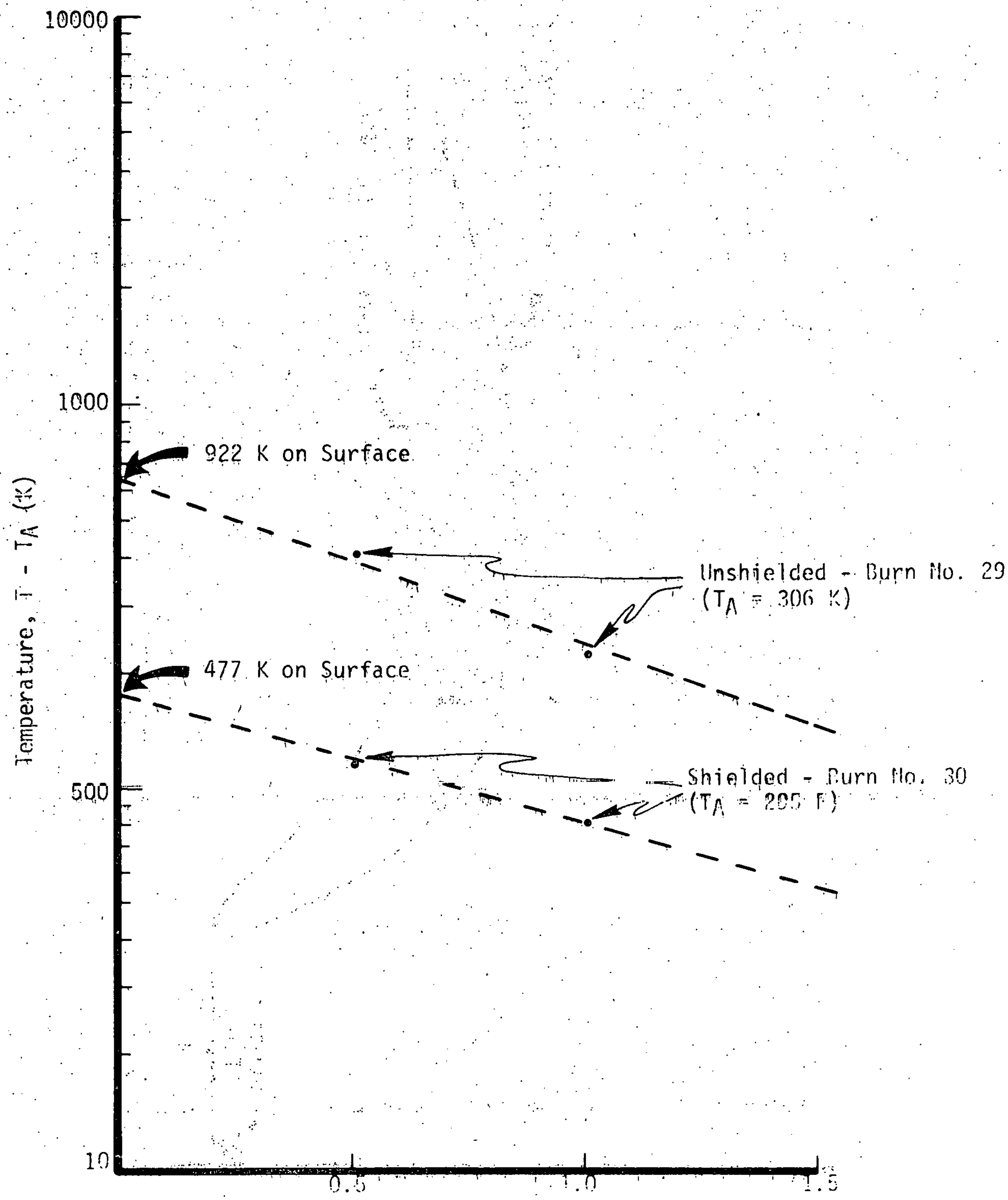

Fig. 11. Concrete Wall Temperature Above Ambient Temperature With and Without Shielding for Radiant Heating

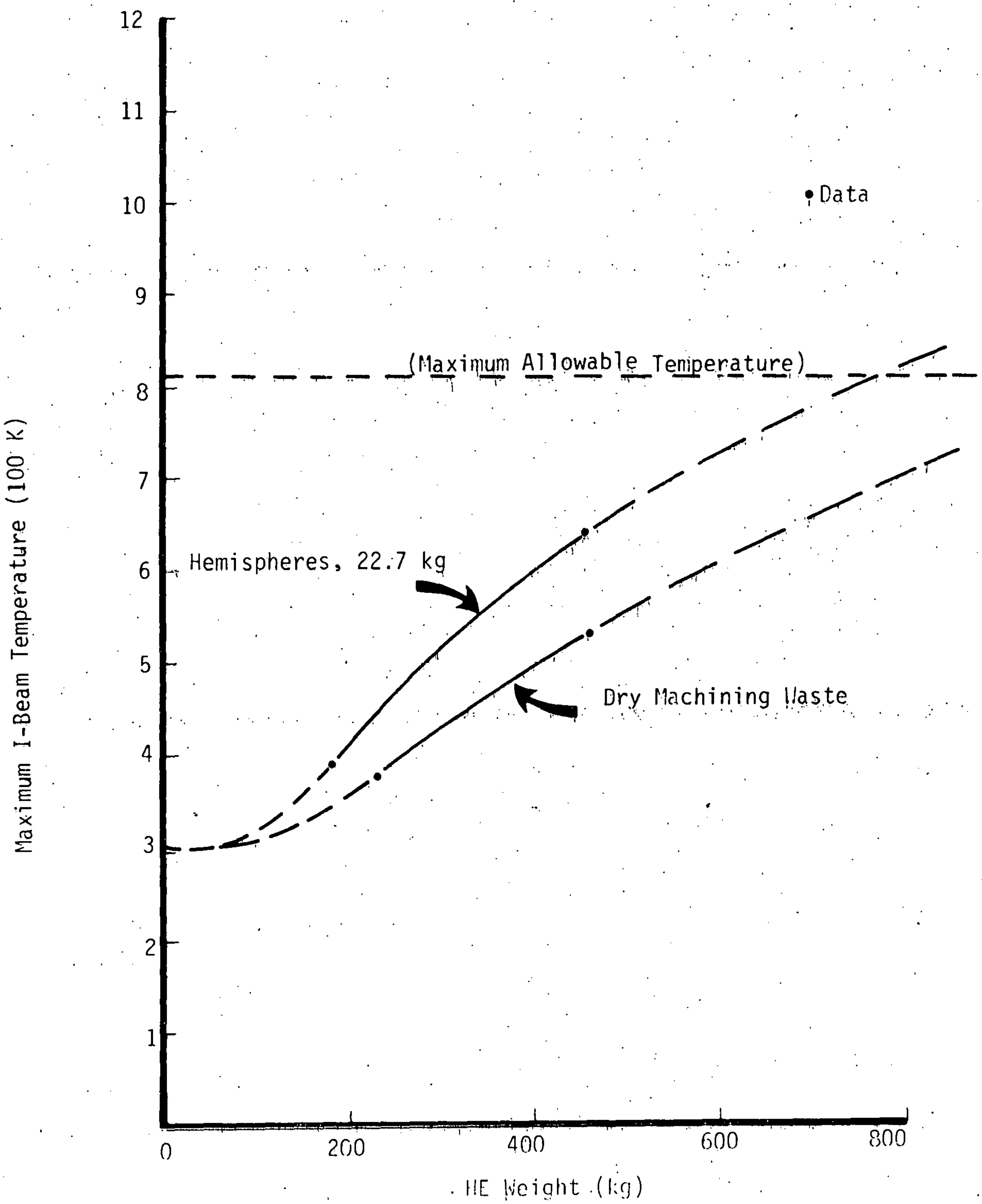

Fig. 12. Maximum I-Beam Temperature Versus Amount of HE for Two Different Burn Rates

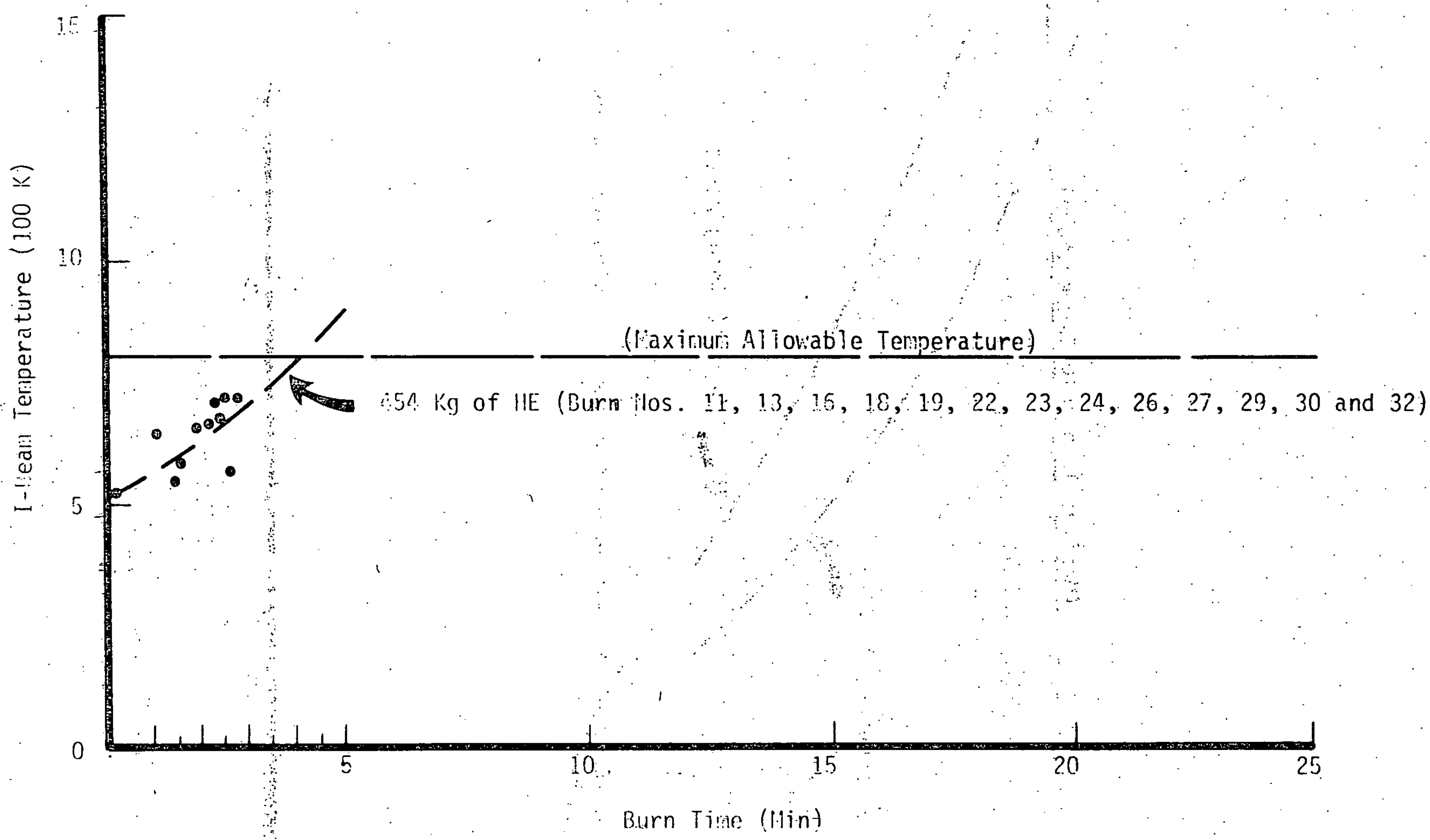

Fig. 13. Maximum I-Beam Temperature Versus Burn Time

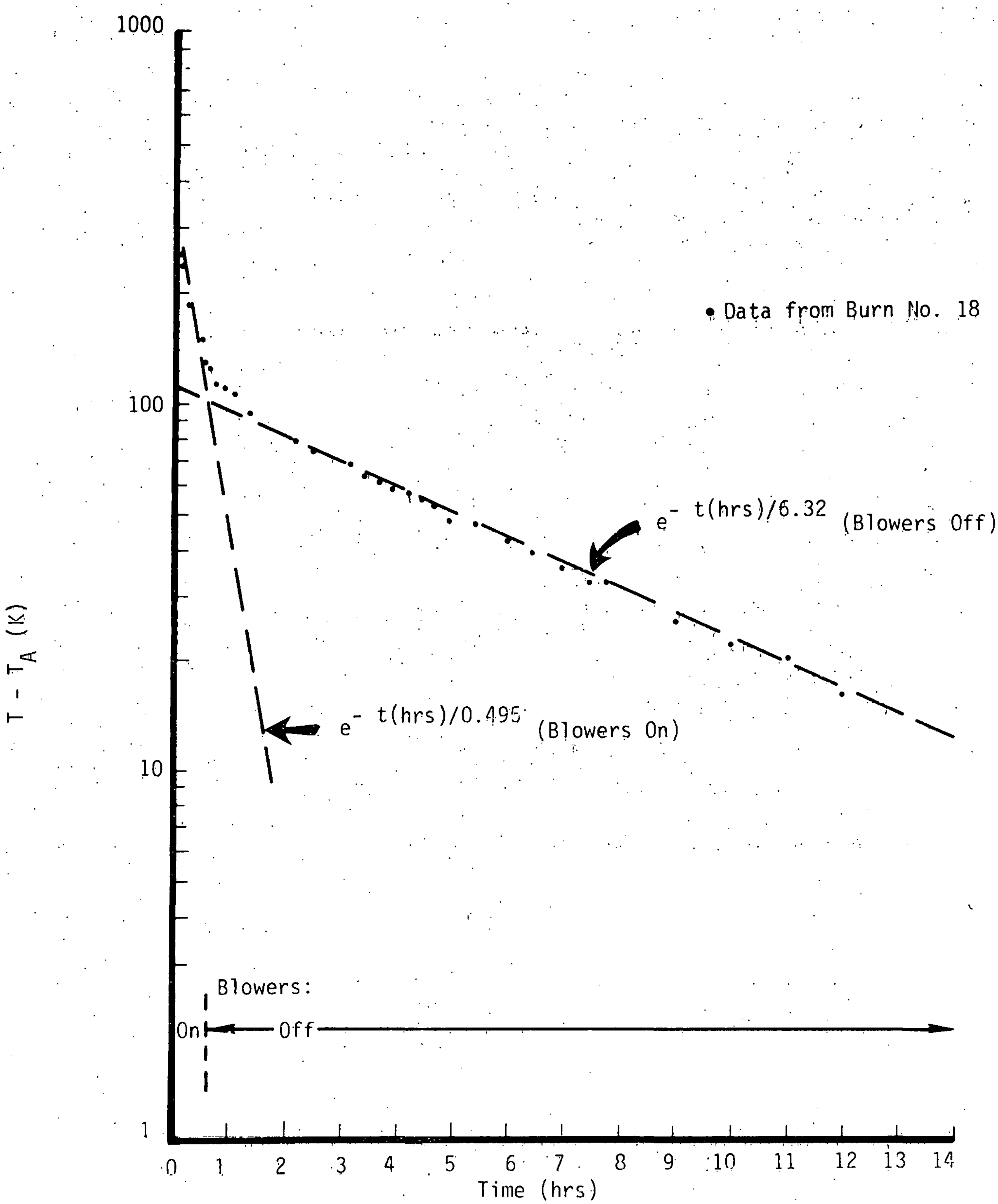

Fig. 14 . I-Beam Temperature Versus Time
Ambient Temperature, T_A = 302 K

The temperature of the concrete wall was measured at 1/2 and 1 cm depths. The maximum temperatures measured at the respective depths are listed in Table IV along with burn number, amount of HE, burn time and the time required to reach the maximum temperature. The analysis parallels that for the I-Beams and for much the same reasons. The larger the amount of explosives and the slower the burn results in higher wall temperatures.

All burns consuming more than 225 kg of explosive in less than 30 seconds will probably vent (flames observed in roof area) and hence pollution effluents will be increased.

Burning dry LX-04 machining waste will cause venting. However, the machining waste is not normally dryed but rather is burned with some moisture content. Hence, the very high burn rates, causing venting in the FST facility, are not normally encountered in the HE waste disposal program of the plant. However, this disposal design is limited to burning rates below 20 kg/s in order to maintain filter integrity. It is to be noted that the sand-gravel is self-repairing should venting occur.

Phase II yielded the following design criteria.

1. Air temperatures within the incinerator were appreciably below that of the fire ball temperature ($\sim$ 1900 K). This is mainly due to cooling by mixing with the outside air (via the blowers) and by heat radiation to the interior surfaces. Heat transmitted within the incinerator can be expected to be proportioned 1/3 by heat radiation and 2/3 by heat convection.

2. The gases within the incinerator contain approximately 15% water by weight and coupled with the burn products (specifically, NO) should be considered acidic in their effect on the interior surfaces. However, no detrimental effects were observed.

3. Air flow through the sand filter raises the temperature of the sand a few hundred degrees and the air temperature a few centimeters above the sand is only a few degrees above ambient (if venting occurs then temperatures for short periods of time may exceed 573 K above the sand).

4. The temperature of the overhead I-Beams were considerably below the maximum allowable value of 810 K. This is true for most of the burn conditions anticipated for a HE waste disposal facility. However, if an extended burn time were to occur the temperature of the I-Beams might well exceed 810 K.

Table IV. Concrete Wall Temperatures

Burn No.	Amount of HE (kg)	Burn Time (s)	W1 (5 mm Depth) Maximum Temperature (K)	W1 (5 mm Depth) t_{MAX} (s)	W2 (10 mm Depth) Maximum Temperature (K)	W2 (10 mm Depth) t_{MAX} (s)
15	232	16	540	40	390	230
16	459	90	670	90	480	220
17	136	9	470	50	350	180
18	454	130	720	180	510	350
19	465	13	550	40	370	190
20	455	26	690	70	420	220

5. It would be possible to reuse the incinerator several times in one work shift by leaving the blowers on. The temperature of the I-Beams can be lowered to ambient temperature in approximately two hours after the burn.

6. The I-Beams deflect (sag) elastically during HE burning. These deflections, in some cases, exceeded 2 cm. The long-term effects of repeated deflections of this magnitude are not known. This should not be taken as a severe limitation to the closed-pit batch-type incinerator concept since there are several solutions to this problem, if indeed such a problem exists.

7. Scaling was observed on the surfaces of the I-Beams possibly due to a combination of a higher rate of oxidation at the high temperatures and a moist and acidic environment.

8. Concrete wall temperatures were very high and showed some signs of spall. Surface temperatures reached 922 K and a powdery texture was noted on the walls. The fire brick walls and liners showed little effects from the heat.

9. The pressure excursions during a burn indicated no venting through the filter except for extreme burn rates ($\geq$ 20 kg/s). This was also verified by the 16 mm film records.

10. Finally, the forced air flow rate (9.4 m^3/s total) appeared adequate. It would not be desirable to reduce this flow since air temperatures would rise with corresponding rises in I-Beam and wall temperatures. However, these temperatures could be reduced by increasing the flow rate.

Phase II was completed in September 1975.

The primary objectives of Phase III were: (1) to determine what con-concentration of pollutants are produced and to what degree the production of these concentrations can be minimized, and (2) to study the effectiveness of the overhead filter in reducing the effluents (NO, NO_2, CO and particulates) produced.

A preliminary evaluation of burn products from various explosives indicated similarities in kinds of burn products and concentrations. Therefore, for the evaluation of the parameters which affect gas production (oxygen requirements and dwell-time of burn) and the evaluation of filter effectiveness, a single kind of explosive (with the same exposed surface area for each burn) was used. This served as a control for the burn products and burn-rate while other parameters were being changed. Granulated LX-09 (and in some cases LX-04) was used. The surface area is fairly uniform, it burns fast and uniformly but not too fast to breach the overhead filter, and the availability of this explosive was good. Each burn consumed approximately 454 kg of explosive.

The levels of NO_x and NO were not excessive ($\leq$ 1000 ppm) for the gas monitors used; however, this was not the case for the CO measurement. The concentration of CO produced within the incinerator was beyond the capability of the instrument and it was necessary to dilute the sample by a known amount. Flow meters were used in both the sample line and the line supplying the fresh air. The time dependent flow data were folded into the time dependent gas-sampling data.

A preliminary estimate was made for the filter effectiveness. There appeared to be a slight decrease in NO_x as the gases pass through the sand. The main component of NO_x is NO which is relatively unreactive with a filter media such as sand. The data are not as conclusive for CO. However, a slight decrease in CO may exist above the filter. It must be realized that filter effectiveness depends to a large extent on the production parameters. If, for example, CO could be reduced by increasing NO_x and at the same time NO_2 could be made the dominant component in NO_x, then the filter would bring about a sizable reduction in emissions (via moisture in the filter).

Table V lists the results for Phase III. Initial concentration levels of NO_x and CO within the incinerator are appreciably above the maximum allowable emission levels established by the EPA. There is less than 10% NO_2 present.

Fig. 15 presents preliminary results for the effect of the direction of the forced air on CO production. There was no change found in the production of NO_x or in the ratio NO/NO_x.

Burn Nos. 89 - 94 and 98 - 100 were made to determine pollution production as a function of the amount of HE burned. It appears that CO production increases rapidly with an increase in HE whereas NO_x production (or NO/NO_x) remains relatively constant per burn. Thus, to minimize CO small amounts should be burned—just the opposite is true to minimize NO_x production. Very little success has been obtained thus far in changing the ratio NO/NO_x. If NO could be reduced in favor of NO_2 then the NO_2 would react with the moisture in the overhead filter showing a net reduction in the emission of the oxides of nitrogen.

Further study was originally planned for Phase III. A low brick wall was to be built around the HE to change the time at which oxygen reaches the flame. The dwell time for the burn was to be increased by not allowing fresh air to quench the burn too early. There was to be a gradual reduction in the amount of air entering the incinerator and other explosives and HE-contaminated material were to be burned. Such changes in the production parameters, it is hoped, would not only show promise in reducing the overall emissions of NO_x and CO but also reduce the ratio of NO/NO_x.

Table V. Phase III Data Summary

Burn No.	Amount of HE	Burn Time (min)	Ambient Temp. (K)	% R.H.	Burn Rate (kg/s)	I-Beam Temperature I1	Wall Temperature W1	Air Temperature Average (K)	NO_x (ppm) Maximum	NO_x (ppm) 24-Hour Average (0.05)	NO (ppm) Maximum	NO (ppm) 24-Hour Average	CO (ppm) Maximum	CO (ppm) 8-Hour Average
33	430	1.14	301		6.34	625	669	1395	655	0.33			LOST	LOST
34	464	1.17	295	41	6.62	770	671	1401	350	0.28			PINNED	METER
35	475	1.03	290	32	7.69	640	671	1379	330	0.30			PINNED	METER
36	472	1.16	297	22	6.74	LOST	666	1380	230	0.23			PINNED	METER
37	475	0.85	294	20	9.32	647	647	1384	215	0.25				
38	463	1.08	295	23	7.15	642	-	1394	285	0.35				
39	463	1.22	291	∼25	6.34	650	660	1360	268	0.30				
40	463	1.05	294	13	7.35	640	660	1330	275	0.33			60,000	330
41	457	1.17	292	43	6.53	640	621	1360	277	0.32			44,000	170
42	463	0.94	292	∼70	8.18	650	660	1380	282	1.45				
43	463	1.30	277	23	5.94	630	670	1330	337	0.47			FLOW	UNSTABLE
44	463	1.17	293	19	6.62	620	660	1370	403	0.63			18,000	60
45	463	1.19	293	21	6.48	640	620	1330	500	0.72			18,000	69
46	463	1.08	293	17	7.12	640	660	1360	480	0.72			19,000	80
47	463	1.19	281	52	6.48	590	650	1210	502	0.76			5,000	14
48	457	1.28	273	29	5.94	620	-	1280	375	0.60			11,000	37
49	463	1.41	281	25	5.48	610	660	1280	460	0.79			6,500	28
50	463	1.21	284	18	6.37	620	680	1300	475	0.78			2,600	10
51	463	1.47	291	15	5.24	620	LOST	1290	428	0.74			4,500	16
52	463	1.11	292	21	6.98	610	690	1310	476	0.83			3,900	14
53	463	1.19	287	27	6.48	630	690	1300	-	-	442	0.77	6,500	19
54	463	1.30	295	∼10	5.94	640	LOST	1300	-	-	535	0.82	7,800	27
55	463	1.19	291	17	6.48	620	650	1320	485	0.75			7,100	26
56	463	-	282	12	-		-	-	605	0.86			10,400	33
57	463	-	277	31	-		-	-	LOST	LOST			LOST	LOST
58	463	-	284	35	-		-	-	510	0.78			15,600	51
59	463	-	287	21	-		-	-	400	0.65			22,400	87
60	463	1.30	294	11	5.84	610	640	1290	230	0.36			28,600	84
61	463	1.30	296	15	5.82	630	720	1310	185	0.29			32,200	130
62	463	1.40	295	10	5.47	630	650	1280	∼330	0.70			12,000	44
63	463	1.40	301	6	5.72	640	660	1300			260	0.44	30,000	140
64	463	1.20	283	22	6.52	620	470	1330			230	0.36	16,000	59
65	463	1.50	295	25	5.26	640	480	1280			270	0.42	34,800	140
66	463	1.40	301	50	5.58	620	670	1220	254	0.44			LOST	LOST
67	463	1.20	291	19	6.48	630	690	1280	172	0.34			19,200	65
68	463	1.30	286	60	5.49	620	660	1280	195	0.30			LOST	LOST
69	463	1.40	300	22	5.51	600	630	1260	172	0.29			LOST	LOST
70	463	1.20	295	15	6.30	620	650	1280	212	0.36			LOST	LOST
71	463	1.40	295	20	5.72	610	640	1250	266	0.39			LOST	LOST
72	463	1.40	287	42	5.72	630	610	1290	265	0.39			LOST	LOST
73	463	1.40	301	34	5.38	630	650	1280	DID NOT RECORD				LOST	LOST
74	463	1.40	294	48	6.43	LOST	620	1280	215	0.30			LOST CAMERA	
75	463	1.40	301	29	5.58	LOST	650	1290	DID NOT RECORD				LOST CAMERA	
76	463	1.20	302	31	6.48	LOST	670	1250					1,800	3.1
77	463	1.40	304	25	5.61	650	660	1270					11,000	19
78	463	1.20	303	34	6.79	660	650	1270						2.6
79	463	1.20	301	49	6.54	640	660	1220						15
80	463	1.40	301	53	5.32	650	700	1270						2.7
81	463	1.30	302	34	5.94	630	640	1220						36
82	463	1.20	298	52	6.43	640	640	1280						23
83	463	1.60	398	56	4.98	490	550	1130						
84	463	1.20	303	33	6.71	640	650	1210	190	0.35				60
85	463	1.20	302	39	5.94	640	650	1220			200	0.39		120
86	463	1.40	302	40	5.51	690	650	1250	180	0.26				140
87	463	1.10	302	39	6.81	680	620	1280			220	0.32		140
88	463	1.20	303	35	6.34	660	660	1260	190	0.30				6
89	218	1.30	302	42	2.89	480	460	1060	200	0.31				0.7
90	218	0.90	294	62	3.96	510	470	1060			250	0.39		
91	327	1.40	298	43	4.04	600	560	1160	210	0.32				11
92	327	1.20	304	27	4.57	580	520	1160			245	0.32		16
93	572	1.50	297	64	6.20	720	660	1260	200	0.29				
94	572	1.60	293	68	5.50	750	670	1280			210	0.60		
95	463	0.40	288	49	19.70	570	520	1450	200	0.12				260
96	463	1.20	280	44	6.4	670	600	1280	430	0.35			LOST	LOST
97	463	1.30	288	28	5.9	640	610	1280	280	0.25			25,000	29
98	572	1.60	288	30	6.1	710	650	1310	LOST				LOST	LOST
99	572	1.70	294	37	5.7	710	660	1290	285	0.17			LOST	LOST
100	572	1.60	288	35	6.0	710	620	1300			355	0.25	LOST	LOST
101	454	2.40	293	30	3.2	740	620	1150	320	0.47			840	0.99
102	454	2.40	292	35	3.2	740	600	1150			330	0.51	1,680	2.6
103	463	0.60	291	36	13.2	560	530	1420			LOST		LOST	LOST
104	463	0.60	-	-	12.9	580	520	1440			250	0.15	37,800	72
105	463	1.40	291	40	5.5	660	600	1280	195	0.14			32,600	61
106	463	1.40	282	46	5.7	640	620	1280			LOST		LOST	LOST

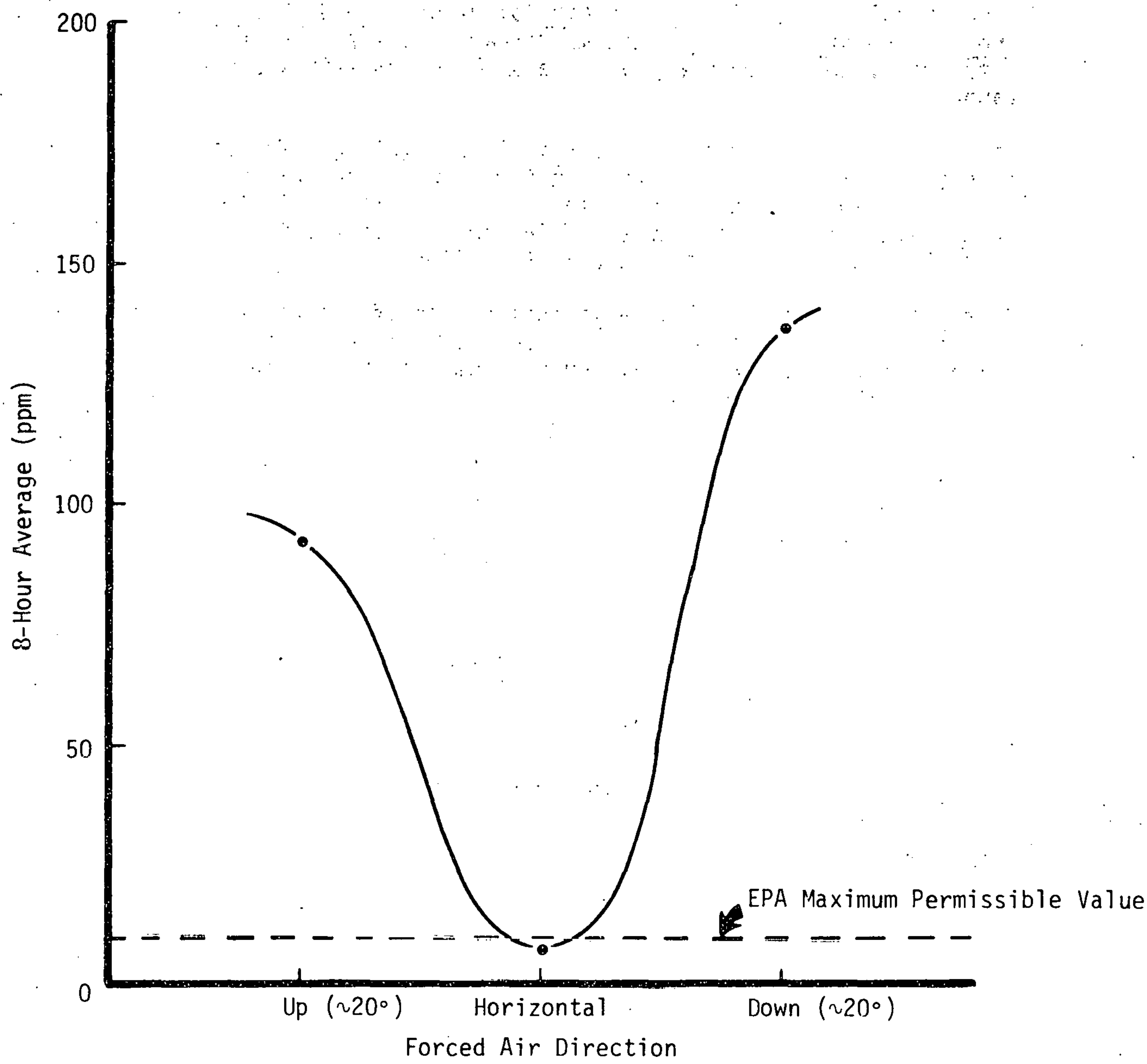

Fig. 15. Effect of (Forced) Air Direction on Production of CO (454 kg of LX-04 Granules)

The emissions from the FST were sampled for particulate matter. The sampling method and procedure is one of high-volume-air sampling for the determination of compliance with emission limits as put forth in Texas Regulation I; Control of Air Pollution from Smoke, Visible Emissions, and Particulate Matter (effective January 19, 1974), Appendix B(C). To date there has not been any visible smoke or emissions other than water vapor.

Table VI shows the results for particulate sampling. Variation of results is expected due to very short burn-times and to the windy conditions that exist in the Texas Panhandle. These results indicate that the particulate emission from the FST incinerator is within the maximum allowable level required by the State of Texas.

As stated earlier the closed-pit incinerator effort was terminated just prior to the completion of Phase III. Phase IV was to develop burning procedures and safety requirements for the incinerator complex.

Table VI. Preliminary Particulate Sampling Results

Burn No.	Air-Sampler Flow (m /sec)	Elapsed Time (min)	Net TSPM[a] (g/m)	
			Measured	Minimum Allowable
25 (Phase II)	0.019	120	137	200[b]
33 (Phase III)	0.017	55	138	400[c]
41 (Phase III)	0.020	56	305	400[c]

[a] *Total Suspended Particulate Matter*

[b] *Maximum Allowable TSPM for a 2-Hour Period - Rule No. 105.22 of Texas Regulation I*

[c] *Maximum Allowable TSPM for a 1-Hour Period - Rule No. 105.23 of Texas Regulation I*

4.0 SUMMARY

The "Disposal of Waste or Excess High Explosives" project began January 1971 with the objectives of (1) to determine the magnitude of the problem associated with meeting the new local and federal regulations at the ERDA facilities and (2) to determine methods for disposal and develop a pilot-scale process for disposal of the waste HE. The projected amounts of waste or excess explosives were determined (∿ 250,000 kg/year at the Pantex Plant) and different methods of disposal were examined during the first part of the project. Open burning, detonation, enclosed burning, deep-well injection, ocean dumping, biochemical decomposition and chemical recovery were investigated. It was concluded that incineration at major ERDA facilities is presently the most feasible and safest method available with the least cost and development time required.

A preliminary design was made for an incinerator complex to be built at the Pantex Plant. Additional information was needed to crystalize the design and two separate investigations began. A rotary continuous-feed type incinerator was investigated at the Burlington, Iowa Plant while at the same time a closed-pit batch-type incinerator was investigated at the Pantex Plant.

The rotary incinerator effort concluded April 1975. The recommendations were that the rotary-type incinerator is feasible and probably could be used to process machining waste or other waste that had already been reduced in size. Pollution abatement would be accomplished through the use of commercial exhaust gas processors. High cost would be a disadvantage in the case of possible detonations. Further investigations were recommended to solve flashback conditions and increase the rate of disposal to the desired level.

The closed-pit incinerator concept (and also the full-scale test incinerator) has been shown to also be a very valid one, especially in disposing of large unprocessed HE billets. Only slight modifications of the full-scale test incinerator would be necessary in order to form a basis for a large incinerator complex. NO_x and CO concentrations are high within the incinerator yet with burn times of only a few minutes, the time-average values are quite low. Further investigation is recommended to possibly reduce emissions and to establish procedures necessary for a production-type incinerator.

A recent grant of authority by the Texas Air Control Board for the ERDA Pantex Plant to conduct outdoor burning indefinitely brought about the termination of the project December 1976.

REFERENCES

1. F. I. Honea, Waste Explosive Disposal Project, MHSMP-70-102.

2. J. Wichmann, F. I. Honea, W. A. Bullerdiek, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-71-55.

3. I. B. Akst, F. I. Honea, Disposal Methods for Explosives, MHSMP-71-60.

4. J. Wichman, F. I. Honea, Disposal of Waste or Excess High Explosives, MHSMP-72-12.

5. F. I. Honea, J. Wichman, Disposal of Waste or Excess High Explosives, MHSMP-71-27.

6. F. I. Honea, J. Wichmann, W. A. Bullerdiek, Disposal of Waste or Excess High Explosives, MHSMP-72-30.

7. F. I. Honea, J. Wichmann, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-72-47.

8. F. I. Honea, J. Wichmann, Disposal of Waste or Excess High Explosives MHSMP-72-73.

9. F. I. Honea, J. Wichmann, E. E. Leake, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-73-1.

10. F. I. Honea, J. L. Barnard, W. A. Bullerdiek, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-73-11.

11. F. I. Honea, W. A. Bullerdiek, J. E. Wichmann, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-73-29.

12. F. I. Honea, W. A. Bullerdiek, Disposal of Waste or Excess High Explosives, MHSMP-73-40.

13. F. I. Honea, T. K. Mehrhoff, Disposal of Waste or Excess High Explosives, MHSMP-74-2.

14. R. D. Worley, T. K. Mehrhoff, J. Wichmann, Disposal of Waste or Excess High Explosives, MHSMP-74-14.

15. R. D. Worley, Disposal of Waste or Excess High Explosives, MHSMP-74-31.

16. R. D. Worley, Disposal of Waste or Excess High Explosives, MHSMP-74-39.

17. R. D. Worley, Disposal of Waste or Excess high Explosives, MHSMP-75-3.

18. Disposal of Waste or Excess High Explosives, Burlington ERDA Plant Final Report, MHSMP-75-14.

19. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-75-15.

20. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-75-29.

21. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-75-52.

22. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-76-6.

23. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-76-10.

24. Disposal of Waste or Excess High Explosives, Development Division, MHSMP-76-18.

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