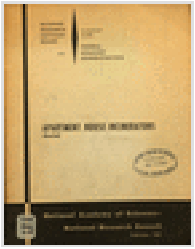

Apartment House Incinerators (Flue-Fed) (1965)

Pages
48

Size
8.5 x 10

ISBN
030936051X

Building Research Advisory Board; Division of Engineering and Industrial Research; National Research Council

BUILDING RESEARCH ADVISORY BOARD

Officers and Members
1964-65

APARTMENT HOUSE INCINERATORS

(Flue-Fed)

Report No. 29 to the
FEDERAL HOUSING ADMINISTRATION

Prepared for
The National Academy of Sciences
by the
BUILDING RESEARCH ADVISORY BOARD
Division of Engineering and Industrial Research
National Research Council

Publication 1280
National Academy of Sciences—National Research Council
Washington, D. C.
1965

The National Academy of Sciences was granted
permission to publish this report by the
Federal Housing Administration

Available through the
Printing and Publishing Office
National Academy of Sciences—National Research Council
Washington, D. C.

$2.00

Inquiries concerning this Publication should be addressed to:
The Executive Director, Building Research Advisory Board,
National Academy of Sciences—National Research Council
2101 Constitution Avenue, N.W., Washington, D. C. 20418

Library of Congress Catalog Card Number 65-60065

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FOREWORD

The Academy—Research Council performs study, evaluation, or advisory functions through groups composed of individuals selected from academic, governmental, and industrial sources for their competence or interest in the subject under consideration. The members serve as individuals contributing their personal knowledge and judgments and not as representatives of other organizations with which they may be associated or of which they may be members.

This report represents the conclusions of the Building Research Advisory Board Special Advisory Committee on Apartment House Incinerators (Flue-Fed). The Committee which prepared this report is composed of recognized authorities on various technical aspects of the problem, who, at the request of the Academy—Research Council, gave freely of their time and knowledge on behalf of the advancement of building technology. The Committee's report was reviewed and approved by a review subcommittee of the Building Research Advisory Board acting for the Board.

BRAB appreciates the contribution that Committee members have made and takes this opportunity to acknowledge their efforts with gratitude. In addition, the Board thanks all who gave assistance to the Committee through either correspondence or personal contact.

Albert G. H. Dietz

ALBERT G. H. DIETZ, Chairman
Building Research Advisory Board

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Section I

INTRODUCTION

Statement of the Problem

Under a contract between the Federal Housing Administration and the National Academy of Sciences, the Building Research Advisory Board agreed to study and report on Apartment House Incinerators (Flue-Fed).

Because of the increased emphasis being placed upon eradication of air pollution, FHA requested advice in two areas:

1. Development of performance requirements and evaluative procedures for apartment building incinerators consistent with reducing air pollution to a minimum.

2. Adaptation of existing or development of new incinerator designs which will ensure meeting the performance requirements referred to in (1) and which will be in all other ways suitable for use.

The Committee appointed to make the study deems the term "apartment incinerator" to refer primarily to the flue-fed unit which has been a serious contributor to air pollution. This report is intended to cover new construction as well as conversion of existing units, and has been prepared on the assumption that the apartment building incinerators relevant to the air pollution problem are, for all practical purposes, the flue-fed units.

Background

Federal agencies have grown increasingly aware of the shortcomings in performance of conventional incinerators such as are installed in multi-story apartment houses, while rising public concern over air pollution has prompted many cities to adopt codes and ordinances intended to limit noxious materials released into the air.

In face of the widespread use of incinerators, there is little agreement among control officials on what performance requirements should be. Existing codes reflect a diversity of opinion and approach. As a result, agencies such as the Public Housing Administration find it difficult to standardize recommendations to local housing authorities responsible for constructing and operating public low-rent housing projects.

The need for reliable technical information prompted PHA to approach the Building Research Advisory Board and the Public Health Service. After an informal meeting, PHS volunteered to gather information on the subject. Meanwhile, BRAB offered its services to convene a committee of specialists who could digest the information available and provide guidance to PHA.

Recognizing that both FHA and the Community Facilities Administration also have an interest in this matter, PHA brought the problem before the Housing and Home Finance Agency's Coordinating Board for Research, Studies and Demonstrations. The HHFA Board considered the subject critical and recommended pursuing the matter with BRAB. Subsequently, a contract was let with the National Academy of Sciences to conduct the study reported herein.

Scope and Limitation

This report deals primarily with flue-fed incinerators; however, the performance levels and test methods recommended are applicable to any apartment house incinerator. Detailed design criteria such as combustion chamber geometry, material usage, and accessories were not part of the study.

Performance levels and test methods are presented, to permit selection of flue-fed incinerators in a manner that takes into account present air pollution problems.

Study Approach

It was recognized that, despite well known inherent limitations, installation of flue-fed incinerators is continuing throughout many parts of the nation. The Committee believed that the current air pollution concerns of the public provided a climate for the establishment of pertinent performance levels. At the first meeting of the Committee, it was established that setting detailed design criteria was neither feasible nor desirable until adequate performance levels are ascertained. Recommendations were therefore limited to the performance levels area, but design approaches that have proven successful were identified. It was concluded that, upon completion of this study, a detailed design analysis could be undertaken, together with a coordinated research effort that could lead to meaningful design criteria.

Special Note

For purposes of this report, a flue-fed incinerator is defined as a system composed of a single or multiple basement chamber with either an integral flue for both refuse delivery and flue-gas exhaust (Figures 1 and 2) or a double flue comprising one flue for refuse delivery and the other for flue-gas exhaust (Figure 3). (These drawings are for purposes of definition only, and should not be construed as indicating all elements or all aspects of geometric configuration relating to good design practice.)

Section II

CONCLUSIONS AND RECOMMENDATIONS

The recommendations which follow are, in the opinion of the Committee, based on the best information and engineering judgment available concerning the problem posed. The Committee wishes to emphasize that experience and the state of engineering knowledge are such that no precise criteria for the design of all apartment house incinerators can be set forth and substantiated at this time. Thus, functions, performance requirements, and applicable test procedures--which are presented in a separate section because of their importance--are covered before a discussion of the state of the art in incinerator design in relation to the performance levels outlined in this report and the way in which operational factors affect design; and finally, there is presented a program of research developed by the Committee, which it believes will provide data needed for optimum incinerator design. The Committee recommends that interested agencies, such as the Federal Housing Administration, Public Housing Administration, Public Health Service, and Community Facilities Administration implement the research recommendations to permit preparation at a later date of meaningful design criteria.

A. FUNCTIONS, PERFORMANCE LEVELS, AND TEST PROCEDURES

1. Functions

The functions of an apartment house incinerator are to:

a. Offer a convenience to tenants.

b. Provide a more sanitary method of refuse disposal than container storage and collection.

c. Serve as a labor-saving device for building owners.

d. Serve as a labor- and cost-saving device for the municipality in reducing the weight and bulk of material which must be hauled from apartment building to final disposition point.

2. Requirements

The flue-fed incinerator can satisfy the above functions only if it:

a. Reduces the refuse to as small a weight and volume as practicable without discharging objectionable gases and pollutants:

A 70% reduction in weight and 90% in volume, with no more than 10% combustible residue, is recommended.

b. Acts as a temporary storage bin for refuse without attracting or harboring rodents or vermin.

c. Remains simple to maintain and operate, with most operations automatically controlled.

3. Refuse Type, Composition, and Amount

a. The incinerator be capable of handling garbage and rubbish up up to a size limited only by the dimensions of the hopper door; larger-size refuse to be charged directly to the basement incinerator.

b. Inflammable refuse such as paint and lacquer containers, aerosol cans (e.g., for spray paint or hair spray), not be placed in flue-fed incinerators.

c. For design purposes, 2 pounds of refuse per person per day be assumed, with a unit weight per cubic foot of approximately 5 pounds, and that refuse be considered to comprise, by weight, 80% rubbish and 20% garbage, with a heat content of 6000 Btu per pound. (Future projections indicate the likelihood of progressively drier refuse with higher heat content.)

4. Incinerator Discharge

The three major air pollutants resulting from incinerator combustion are:

a. Particulate matter such as fly ash

b. Smoke and opaque materials such as unburned hydrocarbons, and

c. Odors emanating from one or a combination of such incineration products.

5. Levels of Performance

It is recommended that:

a. No incinerator be permitted to produce more than 0.85 pounds of particulate matter per 1000 pounds of any flue gas corrected to 50% excess air; for simplicity of measurement, correction to 12% CO_2 may be used.

b. Smoke not be produced in excess of Ringelmann #2 or 40% opacity for more than three minutes in any one hour.

c. No objectionable odors be permitted.

6. Methods of Measurement and Test Procedures for Air-Pollutant Emissions

a. For particulate matter, it is recommended that:

1) Detailed tests for particulate emission be required for a prototype unit (units of similar design need not be tested).

2) ASME Test Codes PTC 21-1941, "Dust Separating Apparatus," and PTC 27-1957, "Determining Dust Concentration in a Gas Stream," be used with the following modifications:

   a) Isokinetic sampling (representative) be obtained.

   b) Sampling nozzles be of at least 3/4-inch inside diameter.

   c) Continuous sampling of CO_2 content of flue gas be performed.

   d) The correction factor for incinerator dust loading be in terms of 50% excess air; for purposes of simplicity of measurement, correction to 12% CO_2 may be made.

b. For smoke, it is recommended that:

The Standard Ringelmann Test Method as described by the Bureau of Mines, Department of the Interior, be used. Acceptable alternative test methods are the Micro Ringelmann Method, PHS Smoke Inspection Guide Method, and the Umbrascope Technique.

c. For odors, it is recommended that ASTM Standard Test Method D-1391-57, "Measurement of Odor in Atmospheres (Dillution Mixed)," be used; however, it must be recognized that the results of this test are subjective and dependent on individual sensitivity, thus limited in significance.

d. In respect to conduct of tests; it is recommended that:

1) A thorough and complete in-place field test of each prototype incinerator be undertaken; this test to allow for:

   a) A range of charging rates from 20% to 100%.

   b) Cyclic firing of combustion equipment.

   c) Varying combustion and flue gas temperatures.

   d) Varying velocities of flue gas.

   e) Various equivalent stack heights.

   f) Presence and absence of auxiliary cleaning devices such as scrubbers.

   g) Auxiliary fuel and power consumption measurement.

2) Capacity, refuse weight, and volume reduction tests be conducted on all incinerators to determine acceptability to standards.

3) The test report detail any mechanical operating difficulties --e.g., with dampers, flue gates, and grates.

4) If other atmospheric pollutant emission tests are required by the purchaser, the Los Angeles County Air Pollution Control District publication, Source Testing Methods, be used as a guide for such testing.

5) Tests be conducted by competent, independent, individual firms in the field of air pollution measurement.[1]

e. It is recommended that, prior to incinerator system acceptance, a report be submitted of the detailed test conducted by a competent, independent facility, in accordance with the provision of d above.

B. DESIGN APPROACHES

1. General

a. Design of new incinerator installations should be placed under the responsibility of an architect-engineer firm having knowledge and experience in combustion processes. Construction responsibility, including flues and chutes, should be placed in the hands of a single subcontractor.

b. Performance criteria should be used whenever possible, even though suggested design and application methods may be outlined in some municipalities.

c. The following are presented as recommended practices based on an analysis of the present state of the art and are not to be considered as rigid criteria.

1) For existing single-flue incinerators, primary effort to improve operation of the unit should be directed toward the combustion chamber, through inclusion of adequate combustion equipment and controls, controlled charging and firing, and automatic operations. Dust control equipment should be considered of prime importance, but should not be solely depended upon to meet the performance criteria outlined in this report (Fig. 1).

2) For low-rise buildings (12 stories or less), use of a single-flue incinerator with by-pass gas flue is acceptable provided that automatic operation is utilized, including locking of hopper doors, batch firing, and employment of adequate dust-collection equipment (Fig. 2).

[1]A partial list of such authorities will be found in Appendix A (p. 36). The Committee strongly urges firms and individuals having competence in this field to make known to the Federal Housing Administration their abilities and qualifications.

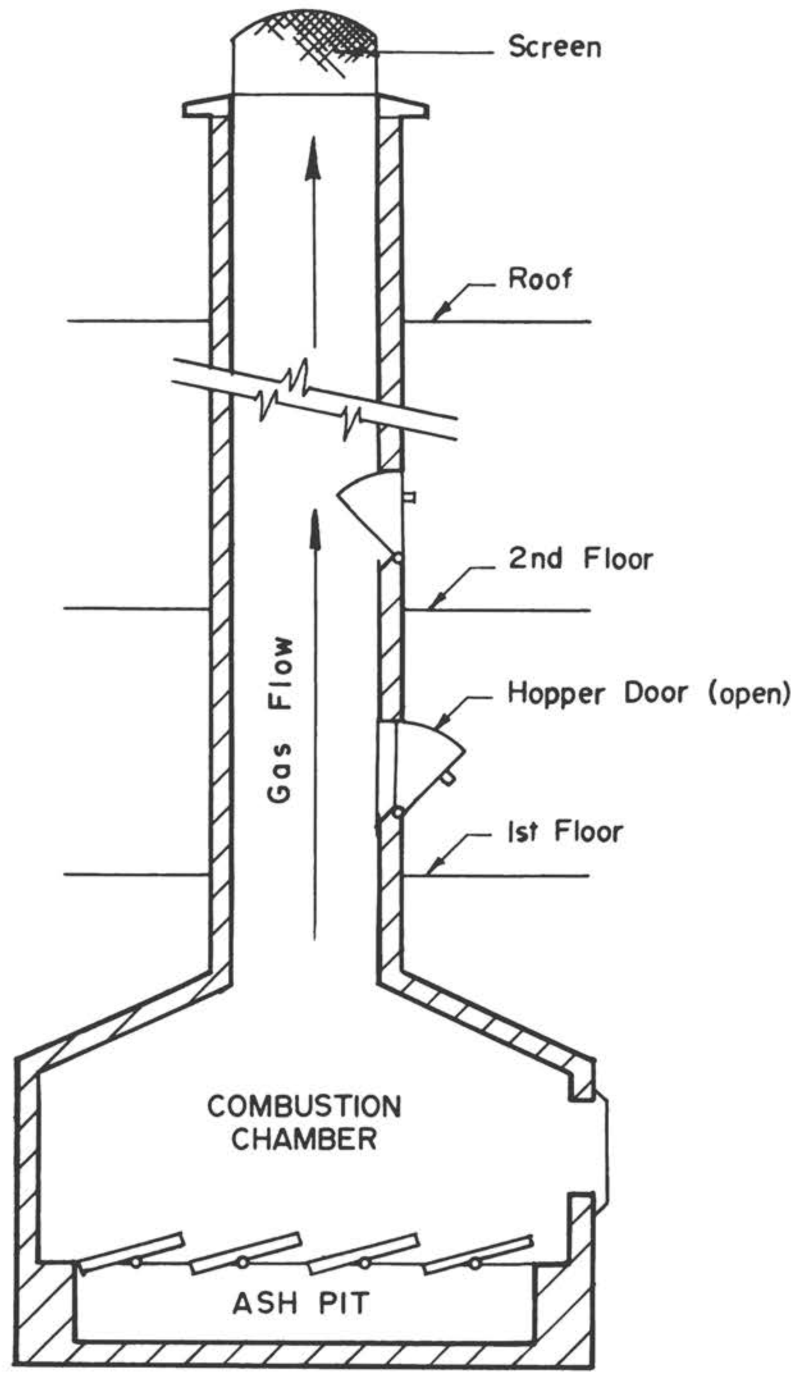

Fig. I. CONVENTIONAL SINGLE-CHAMBER FLUE-FED INCINERATOR

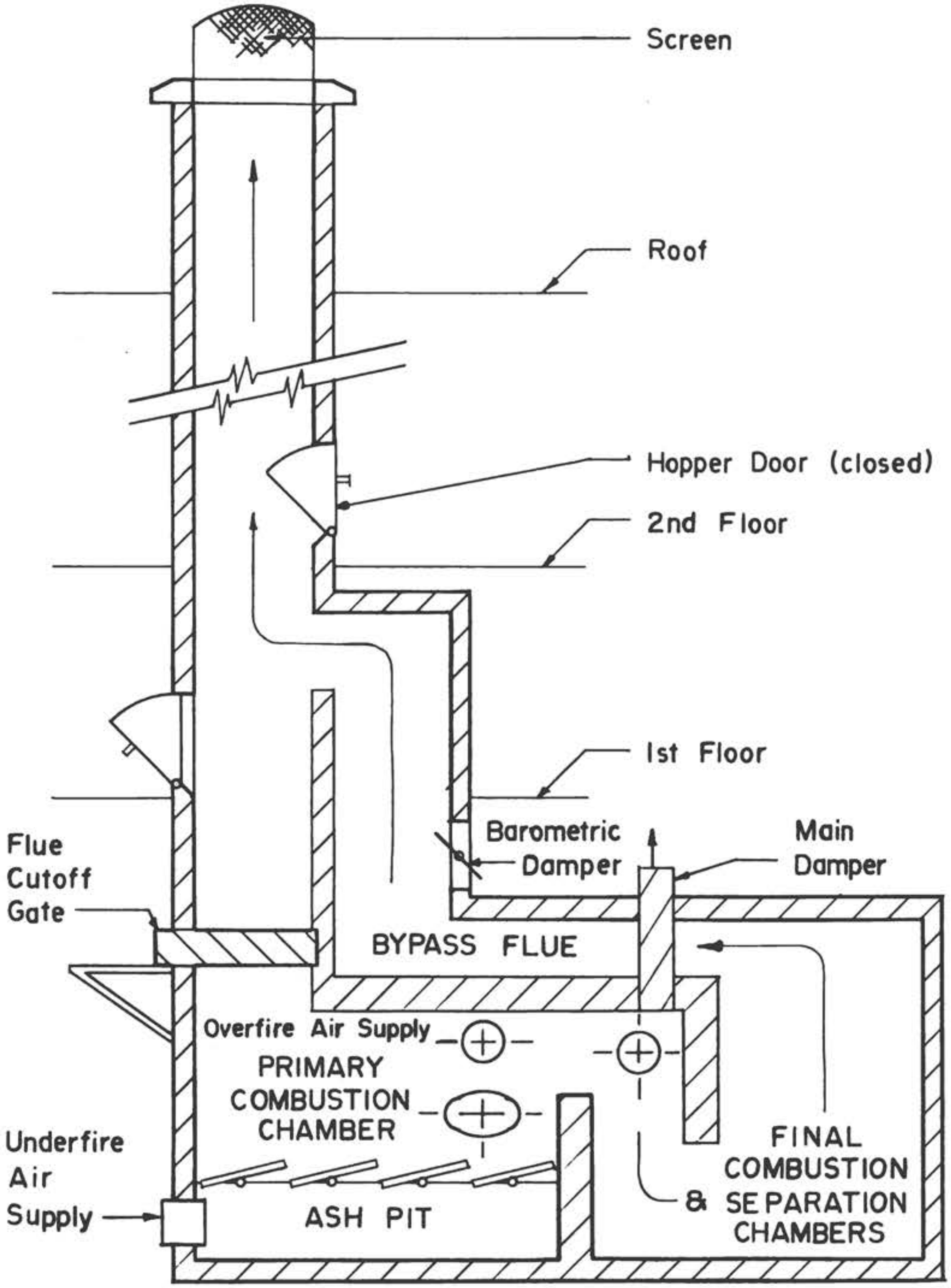

Fig. 2. FLUE-FED INCINERATOR WITH CUTOFF GATE, BYPASS FLUE, SEPARATION CHAMBERS AND DRAFT CONTROL

3) With proper safeguards, flue-fed incinerators of the double-flue design, wherein one flue is used for charging and the other for gas and pollutant exhaust, should be considered for new construction (Fig. 3).

4) Safeguards should include:

   a) Maintenence of negative pressure in charging chute.

   b) Termination of the charging above the roof and the provision of a spark arrestor.

   c) Gas tightness of the smoke flue.

   d) Provision of an induced-draft fan where gas scrubbers are utilized, to assure maintenance of a negative pressure in charging chute and incinerator.

   e) Adequate dust collection equipment.

The following design approaches are recommended where flue-fed incinerators are to be used.

2. Chamber Configuration Sizing

   a. The ratio of length to width (aspect ratio) should be not greater than 2 to 1, and preferably less.

   b. Combustion volume*

      1) Volume for single-chamber incinerators may be calculated on the basis of not less than 0.375 cubic feet per person where the burning period is 10 hours or less.

      2) If a system of controlled automatic batch feeding is employed, heat-release rates of up to 35,000 Btu per cubic foot primary furnace volume may be used, on the assumption that the incinerator is available for burning 17 out of every 24 hours.*

      3) Where burning is limited to 10 hours out of every 24, and the incinerator must store up to 60% of total daily charge, heat-release rates should not exceed 18,000 Btu per cubic foot. This adequate combustion space will be left above the large charge.*

   c. Burning hearth and grate area should be calculated on the basis of not less than 0.075 square feet per person where the burning period is 10 hours or less.*

NOTE: *Values for b and c above are based on 1.44 pound/person/day, with a refuse weight of 4.1 pounds per cubic foot and a heat content of 6,000 Btu per pound.

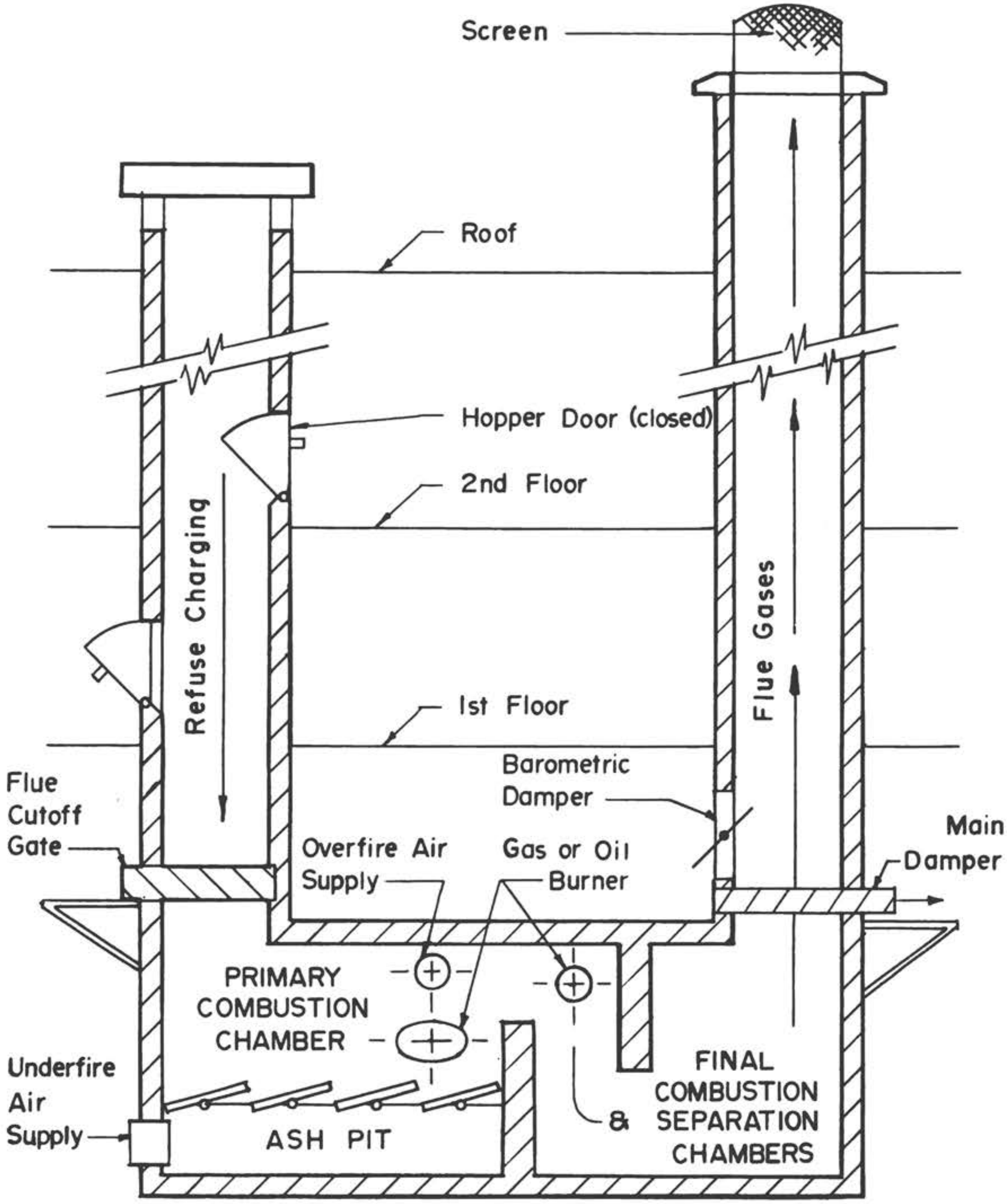

Fig. 3. MULTIPLE-CHAMBER INCINERATOR WITH DOUBLE FLUE

d. The hearth directly beneath the charging chute should be pitched at a 60-degree angle from the horizontal.

e. All surfaces of the primary chamber should be of heat-resistant materials capable of withstanding temperatures of 1500 degrees without damage.

3. Charging

a. Controlled charging through the use of hopper door locks and/or main flue gates should preferably be employed.

b. Where intermittent charging is utilized, it may be assumed that 60% of the total refuse will be delivered between the hours of 5 p.m. and 7 a.m. and consumed during the first burning of the day.

4. Flues and Hopper Doors

a. The charging chute should be connected directly to the chamber with no changes in direction or offset, and should be so located as to provide good refuse distribution over the hearth and grate. The chute or flue should be smooth, with no protrusions which could cause bridging or blockage. Provision should be made for access to clean the flues.

b. Flues should never be less than 27 by 27 inches; optimum flue size for a single flue is 30 by 30 inches (Fig. 1).

c. In high-rise buildings, if a metal charging flue is used, serious consideration should be given to sound insulation of the charging flue.

d. Hopper doors should be not less than 10 by 12 inches nor larger than 160 square inches.

e. Hopper door locks should be of simple and rugged construction, preferably pneumatic in operation and utilizing a tapered bolt.

f. By-pass flues should be sized on the basis of 30 feet per second maximum gas velocity, based on the use of 200% excess air.

g. The by-pass flue should re-enter the main flue at a level between the first and second service entrances (hopper doors) and should be equipped with deflection rods to guard against the entrance of refuse.

5. Double-Flue Incinerators

a. The main chute (charging) should be sized in accordance with 4b above.

b. The gas flue should be sized in accordance with standard design practice for chimneys, but in no case with gas velocities in excess of 35 feet per second or dimensions less than 8 by 8 inches, based on 200% excess air. With natural draft, gas-flue draft measured at the base of the flue may range from 0.20 to 1.35 inches of water.

6. Combustion Equipment

   a. An auxiliary fuel burner should be installed and located in the primary chamber. It should be of such size and so installed as to provide the necessary temperatures in the primary chamber to consume smoke particles and maintain effective combustion. A secondary burner can be helpful if located in or after the flame port for final smoke and odor incineration.

   b. Overfire air supply should be installed so as to provide moderate turbulence without impinging severely on burning refuse or chamber walls. Such air can be simply and inexpensively distributed by the use of horizontal standard schedule-40 black iron pipe, drilled to provide good air distribution from above. Approximately 60% to 80% of the combustion air should be overfire.

   c. Auxiliary fuel burners should be equipped with an intermittent electric pilot and normal combustion controls, with the temperature actuating and sensing device preferably located in the flame port.

   d. Fixed and automatic barometric draft control dampers should be provided; the throttling damper should be placed ahead of the barometer damper in the hot-gas flow.

   e. Combustion air to the incinerator room should be supplied through a fixed, dependable outside air source. With a long system of duct-work, bird screens, insect screens, etc., a forced-draft fan may be required. If a direct wall louvre or grille is used, air velocities should not exceed 500 fpm through the free area.

7. Dust Control Equipment

   a. Dust control equipment should never be considered as an adequate replacement for good combustion characteristics and design. However, only incinerators that have incorporated effective wet scrubbers have demonstrated performance within the particulate emissions limitation of 4a, p. 11, of this report.

   b. Separation (settling) chambers should not be relied upon for the collection of a major portion of the fly ash produced by incinerators, but only to stop the passage of large pieces of unburned refuse. Roof location should be avoided because of danger of smoking out. In addition, roof separation (settling) chambers have been proved to be a cause of increased explosion hazard.

c. These separation (settling) chambers should, when used, preferably be located in the basement as part of the incinerator; should be baffled to prevent the passage of large particulate matter; and should offer ready access for cleaning and maintenance. Provision should be made for positive draft control to prevent re-entrainment during the cleaning period.

d. Gas scrubbers should be located either on the roof or at the lower level. Gas scrubbers which, as a design principle, force the gases to pass through a flooded water bed or impingement system should be considered satisfactory. In light of a history of poor efficiency, spray-type chambers should be used with caution until performance is proved. Inasmuch as gas scrubbers materially reduce the flue gas temperature and thereby affect the available draft, an induced-draft fan having adequate capacity should be provided whenever a scrubber is used. Condensation of water vapor in the flue may occur under some conditions if the scrubber is located in the basement.

e. An electrostatic precipitator preceded by a wet cyclonic separator, although previously utilized experimentally, should be used with care because of high initial costs, as well as lack of performance, maintenance, and operating cost data.

f. Bag and cyclonic filters should be avoided because of high susceptibility to clogging and plugging.

g. Every incinerator should be equipped, for fire prevention purposes, with a spark arrestor constructed of 12-gauge 3/4-inch mesh stainless steel, with cross-sectional area not less than that of the inside of the chimney to which it is attached. It should have a minimum height of 2 feet 6 inches. If paper might be carried up the flue by the hot gases, the arrestor screen could well be up to 5 or 6 feet in height.

8. Other Considerations

a. Exhausting of corridors should be limited, to guard against smokeout from flues to halls. Forced ventilation with preheated air may be used.

b. The chimney outlet should be higher than any structure within 100 feet. The stack should be at least 10 feet above the roof, 4 feet above the penthouse, or 2 feet above a water tower, and should conform to local building codes.

c. Sprinkler heads may be required in charging chutes to quench flash fires in double-flue incinerators.

9. Operation and Maintenance

a. Every effort should be made to make the operation of an incinerator completely automatic--including controlled intermittent batch burning, with (as required items) hopper door locks, main flue gate, auxiliary burning equipment, overfire air supply, temperature control, and dependable combustion air supply and draft control, plus dust control equipment as needed--to permit extension of the burning period, with resultant lowering of capital cost and better air pollution control.

b. Where scrubbers and/or other dust collection devices are installed, they should be run continuously to minimize maintenance and particulate emissions.

c. A planned operating and maintenance program should be established and rigidly followed. Grates must be kept clean, flues clear, scrubbers clean and checked for proper operation, burner and air supply equipment properly adjusted, and spark arrestors cleared of large pieces of refuse, all on a regular basis.

10. Residue Removal and Handling

Present practices of manual residue handling and removal should be thoroughly investigated as a cause of air pollution, poor housekeeping practices, and objectionable odors. Possible modifications include mechanical agitation of the burning bed and direct discharge of residue to sealed containers and carts.

11. Alternative Methods of Apartment House Refuse Disposal

Other methods of refuse disposal should be carefully analyzed primarily on the basis of economics and performance. It should be noted that all alternative methods involve the use of a flue or charging chute. They are:

a. Conveyance of refuse directly by water from a special large-sized sink opening to a holding tank or collection vehicle in a sealed piping system.

b. Compaction and boiling of chute-delivered refuse into high-density bundles for later pickup by regular collection crews.

c. Authorized on-site incineration where the collected refuse is trucked to a central incinerator either in the building or in the apartment development.

d. Central collection by means of large portable containers, that are loaded by compaction devices, regularly removed by truck, and replaced with empty containers.

e. Pulping, i.e., grinding the refuse materials--varying from paper and cardboard to garbage--with water and then extracting the water from the resultant slurry. The final product is a moist pulp whose volume is about one fifth of the original waste volume.

f. Use of garbage grinders in each apartment, coupled with flue-fed incinerators for the remaining refuse. Without the need to burn garbage, air pollution problems are reduced and flues are much more easily kept clean.

C. RESEARCH NEEDS

1. A major coordinated program of research for incinerators and alternative methods of apartment refuse disposal is recommended. The program should be carefully outlined and carried out under the auspices of an objective scientific body, with the research itself conducted by competent professionals in the field. Financial support should be sought from the Department of Health, Education, and Welfare, Housing and Home Finance Agency, and other agencies concerned with the problem.

2. The research program should concentrate initially on fundamental investigation into the combustion process for the several types of incinerator and the several methods involved. This would cover:

   a. Combustion chambers--design, geometry, size, and burning process.

   b. Auxiliary heat--primarily location and method of heat distribution.

   c. Combustion air--amount, location, effect.

   d. Ventilation effect--flue draft; corridor ventilation; chimney height, size and location; need for pressurized incinerator rooms; smokeouts; and odor control.

   e. Dust control equipment

      1) Separation (settling) chambers--effectiveness, location, size, gas velocity, method of operation, maintenance.

      2) Scrubbers--location, type of cleaning, efficiency, gas velocities, water conditioners, maintenance.

      3) Precipitators--location, efficiency, operation, maintenance.

   f. Handling and transport of refuse and residue.

3. In any research effort, the cooperation of various owner groups should be obtained, so that the necessary on-site investigation can be conducted and correlated.

Section III

SUPPORTING INFORMATION

A. FUNCTIONS, PERFORMANCE LEVELS, AND TEST PROCEDURES

Use of flue-fed incinerators in multiple-story apartment buildings has resulted from the need for a convenient and simple method of disposing of routine household refuse, plus the necessity for larger communities to reduce the load on overburdened municipal collection and disposal facilities. While this method of refuse disposal has helped to alleviate municipal waste disposal problems, it has at the same time created a significant source of air pollution.

In its simplest form, the flue-fed incinerator consists of a single chamber in the basement, a flue with hopper doors at each floor, and a screen at the top of the flue (Fig. 1, p. 7). Initially, the flue serves as a refuse charging chute; the chamber serves as a receptacle for diverse garbage, paper, cardboard, sweepings, metal cans, bottles, cotton and synthetic fabrics, various types of plastic material. During burning of the refuse, the chamber serves as the combustion space, and the flue conveys gases and other combustion products to the outside atmosphere. After burning, non-combustibles are removed from the grate and ash pit to be disposed of by municipal or private refuse trucks.

Such elementary designs have proved unsatisfactory for achieving complete combustion of the refuse, as evidenced by the combustibles found in the residue and the incompletely oxidized materials commonly discharged to the atmosphere. The gaseous pollutants released contain a wide range of hydro-carbons, including highly odorous aldehydes, organic acids, and esters, minor amounts of oxides of nitrogen, plus small amounts of sulfur compounds. These compounds disperse in the atmosphere to become part of the total community air pollution problem. The discharge of fly ash, charred paper, and the odorous materials creates a local nuisance; solids usually settle out close to the source, while the odorants occur in sufficient concentration to cause unpleasant effects (and, in some instances, to produce a probable health hazard).

Problems encountered in the use of the flue-fed incinerators are not necessarily limited to discharge of pollutants to the atmosphere. These incinerator systems sometimes also create objectionable conditions inside the building when smoke and odorous gases from the flue escape into the corridors, a condition commonly referred to as "gassing" or "smokeout."

Air pollution from flue-fed incinerators has brought complaints from apartment house tenants who have experienced smokeouts, from residents of neighboring buildings subjected to the odorous gases and to smoke, soot, and fly ash settling on porches and window sills, and from air-pollution control agencies concerned with reducing both the fly ash nuisance and overall community air pollution.

Despite such disadvantages, the existing flue-fed incinerator has continued in use in some communities because it is simple and convenient for the occupant and economical for the apartment owner, and because it reduces the load on municipal disposal facilities. Much progress has been made in improving operation through the use of multiple chambers, auxiliary burners, overfire air, scrubbers, and induced-draft fans. There are some communities, however, in which existing incinerators have been sealed against further use while new installations of this type have been banned.

1. Functions of Incineration

Health and odor hazards militate against placement of storage containers on the various floors of an apartment to dispose of rubbish. The flue-fed incinerator allows the tenant to dispose of his refuse at practically any time.

Building owners will normally be prepared to accept a principle or adopt a device that can be expected to produce savings. A flue-fed incinerator unquestionably constitutes a significant labor saver to the building owner. In past years, before flue-fed incinerators were in use, it was necessary for a building custodian to pick up refuse from each apartment, then deliver it either to a central incinerator or to central container storage for later removal. Time and motion studies have indicated that an overall average of five minutes of man time per apartment is required to complete this process; the time required can be significantly increased by such factors as tenant slowness in cooperating, lack of freight elevator facilities, and inadequate pick-up services. It can be expected that building owners will continue to utilize the flue-fed incinerator which has proved an excellent investment.

The municipality also has a vested interest in the flue-fed incinerator. Some $20-$25 per ton is the cost of picking up and disposing of the household refuse of a municipality. Simply on the basis of population increase, the projected equipment and manpower needs of municipal sanitation departments are frequently staggering. If the refuse volume can be materially reduced through on-site incinerators, the municipality obviously can perform its function with less equipment and manpower investment.

Such advantages were purchased at the cost of serious air pollution control problems that accompanied the flue-fed incinerators used in the past. With modifications to ensure meeting the performance levels outlined in this report, flue-fed incineration, it is believed, should be considered widely acceptable.

In 1957-58, the American Public Works Association conducted a detailed analysis of twelve cities ranging in population from 4,500 to 8,500,000 people. The pounds of refuse per capita collected on an annual basis ranged from a low of 1,103 to a high of

1,690; the volume of refuse approximated 375 pounds per cubic yard in truckload lots. (These averages do not include San Francisco which collected only 794 pounds per person, because the peculiar method of charging for collection causes deviation from existing national patterns. All other cities collected the refuse, regardless of whether the collection system is financed by service charges or by general taxes.)

From these figures, it can be seen why muncipalities are interested in any on-site incineration process which will materially reduce the volume of refuse. It is interesting to note that the smallest city, with a population of 4,500, has approximately 15% more collected refuse per person than the largest, with 8,500,000. This difference can in part be attributed to the large-scale use of on-site incineration in the large city.

2. Refuse Type, Composition, and Amount

a. Type

Refuse, as a generic term, refers to solid wastes. For apartment house incinerators of the flue-fed type, refuse can be divided into rubbish and garbage. Rubbish is composed of dry combustible material such as newspapers, magazines, cartons, boxes, plastic containers, and non-combustibles such as metals, tin cans, glass, crockery, and dirt.

Garbage is composed of wastes from the preparation and serving of foods. It is largely putrescible organic material with high natural moisture content; removal from the apartment at short intervals is necessary.

b. Composition

The most important factor in regard to composition is the net heating value per unit weight. Two considerations will affect this value: moisture content, and ratio of combustible to non-combustible materials.

The Committee has recommended that, for design consideration, refuse be considered 80% rubbish and 20% garbage, with an average heat content of 4500 Btu per pound.

Data on rubbish versus garbage are meager; however, there is a definite trend to larger amounts of combustible materials such as waxed packages from frozen foods, together with decreasing amounts of garbage. The ratio of rubbish to garbage has risen from the historic 50-50 used in criteria for many years; with the expected continuation of this pattern, there will be corresponding increases in the net amount of heat obtained from the refuse. This tendency is strengthened by the increase in canned foods as against fresh vegetables; although non-combustible, the cans provide a more porous charge in the incinerator which assists the combustion process and makes for better burn-out.

Garbage, being in the neighborhood of 70% wet, provides most of the moisture content in refuse; rubbish moisture content comes to only some 15%. Thus refuse usually holds about 25% moisture by weight. If the materials were dry and free of inert materials such as ashes, the net heating value would be approximately 9,000 Btu per pound. However, this value is reduced by the amount of moisture and non-combustible material present. From many studies it appears that 4,500 Btu per pound is an acceptable design value.

It should be noted that the Committee can find insufficient data to support an assumption that garbage grinders and disposals discharging into sewers have had any effect on the amounts of refuse collected. There are, in fact, many areas of the country where garbage disposal units are not allowed, although most areas permit, and a growing number of cities require, garbage grinders. It is concluded, then, that the use of garbage disposals, per se, will not materially affect these ratios, particularly since the proportion of garbage dry refuse is small to begin with.

c. Quantity

Although the amount of garbage has been reduced, there has been a continuing rise in the total amount of refuse collected. In an affluent society, it can be expected, for example, that there will be more newspapers and periodicals read and discarded. It seems a safe assumption that, as time goes on, the amount of refuse per person will continue to increase. Extensive tests on modern apartment buildings show an average of 1.44 pounds of refuse per capita day, but in some locations this may be as high as 2.0 pounds per capita day.

The unit weight for flue-fed incinerator rubbish is much easier to define than for other types of refuse. Indication is that an average bulk density of 5 pounds per cubic foot in the incinerator is acceptable for furnace design.

3. Types and Quantities of Incinerator Discharge

The primary incinerator air pollutants are particulate matter, smoke, and noxious gases. Particulate matter includes fly ash, soot, charred refuse particles, and tar droplets. Smoke is actually the sub-micronic particles (.001 to 0.2 micron) which are visible to the naked eye. Harmful and odorous compounds, particularly the offensive aldehydes, are also produced. While the offensiveness of odor as such may vary considerably from one individual to another, leaving some people free of discomfort, various gases have been shown to produce measurable deleterious effects on the human organism.

a. Particulate matter

Recently many tests have been conducted to determine the amount of particulate matter produced by a flue-fed incinerator. Some of the initial researchers found that such matter from a single-chamber flue-fed incinerator ranged from 2.5 to 4.7 pounds per 1000 pounds of flue gas when corrected to 12% CO_2. Most other researchers have found similar emission values. However, it has been established that much lower values can be achieved when due consideration is given to design modification, installation, dust collection, and maintenance.

The Committee believes that its recommended value of 0.85 pounds per 1000 pounds of flue gas corrected to 50% excess air can be attained. Although it is apparent that many flue-fed incinerators in service today are not meeting such a requirement, the present state of the art--entailing the use of auxiliary burners, overfire air, draft control, gas scrubbers, settling chambers, plus proper operational practices--has made this goal attainable.

b. Smoke

Smoke of the visible grey type is always the source of many complaints from neighboring structures. Generally smoke or plume opacity is defined by the use of the Ringelmann Chart which is used to grade the density of black and grey smoke (Bureau of Mines Circular 6888). In essence, the density of smoke is compared with lines of various widths on the chart and a number assigned to which the emitted smoke most closely matches. Besides the maximum density and color of smoke, the one important factor that must be included is duration of emission.

In recent years, a refinement has been introduced in smoke test methods to permit grading of colored effluents not measurable in terms of black or grey. This refinement measures the opacity of visual smoke for translation into an equivalent Ringelmann density. Off-color opaque smoke is common in incinerator discharge and should be measured as well as the more conventional types, to ensure that incinerator design is adequate for avoiding smoke emission.

The purpose of establishing a limit on smoke or plume density is to mitigate air pollution. In setting smoke- or plume-density limits, most municipalities make allownaces for periods of startup, momentary equipment malfunction, and similar short-term problems. Various efforts are under way to produce a more scientific method of smoke measurement. To date, two techniques have been investigated--paper tape filters, and photoelectric devices. The photoelectric device has been used for many years in power plants fired with oil and coal. Its major advantage is that a continuous measurement of smoke can be recorded. The high cost and lack of portability of this equipment have been the major deterrents to its use as a field measuring device. Some communities have used the umbrascope and other visual aids in assessing the density of smoke emission. (One pitfall to be avoided, however, is the possible confusion of a water vapor plume with smoke.)

c. Noxious gases

Data regarding gas emission are very limited. There is little doubt that certain of the gases can be detrimental to health and that, as more is learned of the effects, some limitations on these gases will be imposed.

A recent report by the Special Subcommittee on Air and Water Pollution of the Senate Committee on Public Works reports strong evidence that air pollution is connected with a number of respiratory illnesses including chronic bronchitis, pulmonary emphysema, bronchial asthma, and lung cancer.

The effects of carbon monoxide (CO), a colorless and odorless gas of highly toxic potential, are well known. Its concentration needs to be kept to almost non-measurable amounts; recent work indicates that continuing exposure to even relatively low concentrations is physically harmful.

Sulfur Dioxide (SO_2) is an irritant gas which affects the upper respiratory tract; refuse ordinarily contains at least minute amounts of sulfur-bearing compounds.

Objectionable odors provide a concommitant problem which is complicated by the difficulty of objective and the limitations of subjective measurement. Published data are limited, but it can be anticipated that serious complaints will be lodged, and thus it is important that some limitation be placed on malodorous emissions.

4. Methods of Measurement and Test Procedures for Air-Pollutant Emissions

a. Particulate testing

The greatest amount of incinerator-emission test work has been performed in connection with particulate emission. Particulate test methods fall into three general categories. One, which can be described as the American Gas Association or American Standards Association testing scheme, has been used almost exclusively in the performance testing of domestic incinerators not exceeding 4-bushel capacity; it is thus not generally applicable to flue-fed incinerators. The second involves the low-rate sampling technique (less than 2 cfm); this is a modification of the procedures outlined in the Western Precipitation Corporation Bulletin WP-50, "Methods For Determination of Velocity, Volume, Dust and Mist Content of Gases." The third is the high-rate sampling technique (greater than 2 cfm); this is a modification of the procedures outlined in the ASME Power Test Codes PTC 27-1957, "Determining Dust Concentration in a Gas Stream," and PTC 21-1941, "Dust Separating Apparatus." While varying in detail, all test methods entail:

1) Securing a truly representative sample of the gas and suspensoid from the main gas stream.
2) Filtering of the particulates from the sampled gas stream.
3) Accurately measuring the sampled gas volume.
4) Making such other measurements as are necessary to assess the total emission characteristics. These include temperature, pressure, gas velocity, gas composition, gas molecular weight, and density.

The main divergence in technique occurs in the securing of a truly representative gas and particulate sample. The problem of securing a representative gas and suspensoid sample would be eliminated if the total gas flow could be used as the sample stream; this approach is made impracticable by instrument size and portability requirements. Unless a truly representative effluent sample is secured, any of the methods will produce meaningless answers, no matter how refined and accurate are the mechanics and techniques applied to the other three basic test requirements (2-4 above).

The very nature of the AGA/ASA test facility and method forecloses usefulness for all size ranges of incinerator; the technique was designed to evaluate contribution to air pollution under highly defined conditions of design, construction, and operation, and with particular types of refuse material. The method does not lend itself to widespread usage in commercial, industrial, and municipal incinerators, because of physical size, the great number of incinerator installations constructed "on-the-spot," the lack of design standardization as a result of widely varying needs and requirements, the wide range of composition of refuse handled, and the wide range of operating procedures practiced in field installations.

Because of widely varying particle size and chemical composition of incinerator particulates, special emphasis must be placed on the problem of securing representative gas and suspensoid samples for testing. As long as most air-pollution dust-loading limitations are directed at the nuisance-producing potential of the effluents rather than at health effects or other aspects, it must be possible to assess such potential by any test method proposed as a standard. This requires the sampling of the large-sized incinerator char particles, which are most frequently a cause of incinerator particulate complaint, as well as the smaller-sized particulates. It has been recommended in this report that sampling nozzles be of a minimum of 3/4-inch inside diameter in order to capture and sample most incinerator char and flake material. The larger the size of the sampling nozzle used, the less the likelihood of biasing against the larger-sized particulates. Work conducted by Armour Research Foundation (now IITRI) at the Chicago Calumet Incinerator has substantiated and corroborated this biasing effect in the use of small-sized nozzles for sampling incinerator particulates.

Sampling location is an important consideration in any particulate testing. It is even more important in incinerator testing where sizable percentages of the particles are above 44 microns in size. Both the ASME Test Codes and the WP-50 Bulletin recommend sampling in vertical flow ducts. In incinerator installations, this usually means the stack. Sampling at such a location reduces the possibility of error introduced by dust and gas stratification. There is no substitute for experience in selecting a suitable sampling location. Some incinerators provide relative freedom from stratification in 3 to 5 stack diameters above the top of the breeching saddle, whereas others have required 5 to 10 stack diameters to produce the same results. Horizontal ducts and breechings of incinerators are particularly prone to dust stratification problem. Accessibility and room for freedom of movement at a sampling location are among important considerations in the placement of test openings.

Even with proper selection of the sampling location, it has been found important that ample and adequate traversing of the stack or duct be performed. The ASME Test Codes recognize that adequate traversing of the stack in dust loading and velocity tests is necessary. The suggested minimum number of sample points outlined in the ASME Test Codes for various cross-sectional areas appears to be satisfactory. The need for additional sampling points in traverse of a stack or duct for any particular test is a determination best made on the basis of each individual situation.

Sampling where the temperatures are above 600°F in an incinerator system requires water-jacketed stainless-steel probes. Water jacketing preserves the sampling probe and reduces the likelihood of error caused by the corrosiveness of the sampled gases; it cools and reduces the combustion losses of the sampled particulates, which normally contain many glowing particles; and it permits the use of lower temperature-range filtration media.

A problem peculiar to incinerator sampling is the relatively low concentration of particulates encountered and the high percentage of water vapor present in incinerator emissions. The combination of these two conditions, along with others, makes the selection of the filtration system and filtration medium a difficult one. The necessarily high gas-volume sampling rate, the relatively low dust concentration, the high moisture content of the gases, the need for high separation efficiency at relatively low pressure drop, the weight stability of the filtration medium, the ruggedness required for field usage, the high gas temperatures, and the need for test system portability are among considerations that go into the selection of the filtration device and filtration medium. It has been suggested that a dual filtration system, consisting of a small-diameter cyclone followed by a fabric filter, is a satisfactory compromise arrangement. The cyclone tends to precipitate the larger-sized particles from the sampled gas stream while also serving as an entrainment separator for any condensed or entrained moisture. This permits use of the filter medium without undue pressure buildup due to condensation. This arrangement,which is particularly suitable for evaluating wet-scrubber dust collector systems, requires a careful filtration medium weighing technique to minimize errors caused by the hygroscopic tendencies of a fabric filter. Measuring the sampled gas volume by the ASME method entails use of orifice-type gas metering devices. This method is satisfactory if proper precautions are taken to ensure the accuracy of the equipment used.

The test method previously discussed in light of present ways of expressing results per excess air or carbon dioxide adjustment or correction is not adequate for making supplementary measurements needed to complete a dust loading determination. Most dust loading limitations being enforced by air-pollution control agencies these days include provision for some such correction. Any test method for measuring particulates in incinerators must take cognizance of rapidly changing gas analyses and of excess-air conditions encountered in the incineration process, particularly with presently used incinerator designs and operating practices. It has been suggested that continuous carbon dioxide analysis and/or continuous oxygen analysis equipment is desirable for accurate assessment and measurement of these variations. Use of the continuous gas-sampling equipment should be backed up by regular Orsat flue gas analyses. Recording equipment is not readily portable and is often not sufficiently rugged to withstand the rough treatment and the conditions encountered in field testing; it also adds appreciably to the cost of making a test determination. An alternative to continuous recording is the collection of an integrated sample in an inert plastic bag, with the sample flow maintained proportional to the stack flow. This can be made difficult, however, by the abrupt and frequent changes in flow characteristics of incinerator systems.

b. Smoke testing

Tests for smoke are discussed under Types and Quantities of Incinerator Discharge, page 19.

c. Odor testing

Only a limited amount of work has been conducted on odor testing of incinerator effluents, except in domestic incinerator size ranges. In the domestic incinerator field, odor measurement and testing have been performed principally by using the AGA/ASA open burning-newspaper technique. In this method, three investigators smell the gases produced by the burning of two sheets of newspaper in an open container,then, at 15-minute intervals, enter the incinerator test room from the outside to make comparison with the odor from the gases aspirated from an AGA test stack. This test method obviously suffers from the inconsistencies, differences, and subjectivity of the human olfactory mechanism. Modifications of the AGA incinerator-odor panel technique have also been described in the literature, but all such systems rely on the human nose as the test instrument. The newest (and a most promising) odor-measuring technique developed for domestic gas incinerators was recently reported by Battelle Memorial Institute. In this method, it has been demonstrated that the carbon monoxide (CO) concentration in incinerator emissions may be used as a valid, objective indicator of the odor intensity of domestic gas-fired incinerator effluents when burning an ASA domestic waster charge, including both the olfactory (smell) and trigeminal (pain or irritation) components.

In the commercial incinerator field, a more quantitative concept of odor measurements is the ASTM Standard Method for Measurement of Odor in Atmospheres (Dilution Method) D 1391-57. In this method, a sample of the gas whose odor is to be measured is diluted with odor-free air until a dilution is reached in which the odor can barely be perceived. The ratio of the total volume of this diluted sample to the volume of original sample indicates odor intensity.

This technique assumes that the odor concentration is to be measured without regard to the material or materials that cause the odor, or the concentration of the causants. It also does not take into account the character of an odor. A number of investigators have reported that a relationship may exist between the concentration of carbonyls (aldehydes and ketones) in incinerator effluents and odor levels. From such findings, it would appear that an incinerator-odor test method based on the ASTM test method is generally acceptable for flue-fed incinerators.

5. Conduct of Test

Complete and thorough testing of incinerators is a time-consuming, expensive operation. Yet, if performance is to be the primary criteria for acceptance, testing is necessary.

It is not believed that each and every incinerator system installed needs to be subjected to in-place tests as complete and thorough as those recommended in this report. Rather, the prototype model, including incinerator, flues, and all auxiliaries, is the one that must be completely tested; only limited tests are required for later installations. Tests for incinerators installed after the testing and acceptance of the prototype system should be limited to air-pollution control requirements, specifically for particulate concentrations, smoke emission, and odors. In this way, the costs of testing can be kept consistent with the total costs of the incinerator system.

It is essential that any difficulties encountered during the tests with mechanical equipment, such as dampers, gates, and grates, be reported. Many incinerators have been installed that meet performance levels, but failure of mechanical equipment has resulted in poor combustion control and customer dissatisfaction. One typical result is the effort to fabricate and install home-made barometric dampers which actually require careful, expert design.

The question of who should conduct tests was carefully reviewed before the recommendations in this report were presented. Only a limited number of personnel other than those from Government and state laboratories have been found to be available. In May 1961, a subcommittee of the Incinerator Committee of the Air Pollution Control Association conducted a survey among individuals and organizations with experience in the measurement of incinerator particulate matter and odor emissions; the results underlined the fact that only within a very small group is there firsthand knowledge, familiarity, and experience in the incinerator field. Because of the great emphasis being placed on air pollution performance today, the Committee feels it would be remiss in its charge if it did not identify the firms or individuals known to have the required competence; the list appears in Appendix A, p. 36. It is suggested that those having competence in this field make known to the Federal Housing Administration their qualifications and interests.

B. DESIGN APPROACHES TO FLUE-FED INCINERATORS

1. General

The state of the art and the technology of incinerator design are undergoing a process of continuing change. With emphasis on air pollution abatement, additional engineering effort has been directed toward the control of such pollution sources as flue-fed incinerators. Since the incinerator is in itself a combustion device, the design should be the responsibility of the consulting engineer, to preclude such shortcomings as failure to provide either for adequate combustion air or for offsets in the charging flue, with resultant flue blockage and consequent breakdowns.

From the viewpoint of air pollution, the flue-fed incinerator--because of the heterogeneous nature of its charge and its widely varying rate of combustion--is a marginally acceptable device. Widely varying drafts due to operation of hopper doors, and low-quality operation and maintenance, contribute to poor performance. The problem became critical because minimum cost in the past has been the basic criterion in design of these units, and little attention was given to the factors fundamental to good combustion. In most cases, the combustion chamber was no more than an enlarged brick chimney with little or no refractory. This circumstance has forced some of the progressive code and air pollution authorities to require specific, detailed design and material criteria, based on the best available information. These criteria have accomplished much to improve the operation of flue-fed units, and have led the incinerator, combustion, and auxiliary-equipment manufacturers to conduct extensive research and development in order to produce workable systems.

The Committee prefers the performance approach to incinerator design, whereby, through a series of definitive tests and performance levels, assurance can be presented that the device will operate satisfactorily. The Committee believes the approach is practicable, especially where a series of the same incinerator design are to be used and extensive prototype testing can be conducted. However, the Committee realizes that, in many cases, the present state of the art is such that definitive criteria will have to be utilized in some municipalities.

2. Combustion Chamber Sizing

There is little doubt that complete combustion of waste materials can be brought about, but it is very difficult to achieve in a single combustion chamber--primarily because of inability to maintain a high and uniform temperature in the combustion chamber, inadequate or incomplete mixing of the volatized gases with combustion air, relatively short retention time for the gases in the combustion area, and the heterogeneous nature of the fuel. The single-chamber design is, consequently, considered unacceptable for new construction in terms of air pollution control, and should be discouraged. Where existing single-flue incinerators are to be retained, certain modifications can be made to attain optimum performance; these are discussed in various following sections of this report.

The preferred design is the multiple-chamber incinerator, with the primary chamber acting as a storage container and as an ignition and combustion chamber, while the subsequent chambers permit the completion of combustion as necessary and act as fly-ash separators.

It has been found from practice, experimental testing, and evaluation, that one acceptable type of configuration has a length-to-width ratio in the primary combustion chamber of between 2 to 1 and 1 to 1.

Calculation for volume and burning-area requirements are at best based on empirical values; those included in this report are in common use.

3. Charging

In both the single- and multiple-chamber flue-fed incinerator, the method of charging will materially affect sizing and the ability to control air pollution emissions. The common practice for many years has been to allow the refuse to be charged during the entire day and then consumed in a single burning. This practice is bound to result in poor combustion and severe air pollution, since: a. In spite of the great mass of insulating refractory, the combustion walls cool between charges; b. Additional charging during operation may smother the flames so that the volatized gases are not completely burned; c. An adequate air fuel ratio cannot be maintained; and d. The agitation created results in heavy particle generation.

Within the last few years, air pollution authorities have recognized this problem and have been enforcing regulations which control the times at which firing is permitted. In general, the rules permit incinerator operation during the daylight hours so that visual emission checks can be used for enforcement; even more important, night atmospheric effects are greater because of more stable atmospheric conditions, and windows are generally left open. The present state of the art strongly encourages control of operation through automatic equipment such as hopper door locks, gas burners and cycling clocks, power flue gates, combustion air control, and furnace temperature and draft control.

When a flue gate is used in conjunction with a single-flue incinerator, it is necessary to install a by-pass flue which reconnects with the main flue between the first- and second-floor hoppers. An advantage of this type of design is that the dust-bearing particles must pass through separation chambers where some fly ash may be trapped, and high-temperature retention time is increased.

4. Combustion Equipment

a. Burners

The heterogeneous nature of refuse is such that the heating value, moisture content, and amounts of non-combustibles will vary considerably. Since refuse obviously cannot be considered a reliable fuel, an auxiliary burner should be installed to ensure temperatures adequate to achieve complete combustion. This burner can be thermostatically controlled.

Several locations for the burner have been tried with some success. The best location appears to be above the grate area so that the flame envelope radiates to the burning bed and adds heat to the combustion gases. Limited success has been achieved with the burner located at or beyond the flame port in single-chamber units.

Burners have also been located with questionable success within roof settling chambers, but the cost of reheating the flue gases is considered excessive.

In multiple-chamber incinerators, a relatively new design approach utilizes two auxiliary burners--one in the combustion chamber, which assists in igniting and burning the waste; the other at or beyond the flame port, which incinerates the volatized gases and carbonaceous solids.

b. Air supply

There has been a significant change in design philosophy for introduction of combustion air. In most of the older installations, the largest part of the combustion air entered from beneath the grates, resulting in turbulence and active disturbance of the burning bed. It was literally impossible to prevent creation of massive particulate effluents. Recent research has indicated that most of the air should be supplied over the fire. This approach has resulted in significant increases in combustion efficiency and reduction of effluents. A suggested optimum ratio of overfire to underfire air appears to be approximately 80% to 20%, but provision for adjustment should be made.

Since the combustion process may be poor, excess air must be supplied. The amount should probably stay within the range of 150% to 300%. The excess air is controlled by the draft, which may be regulated through barometric and throttling dampers. In high-rise buildings, troubles have been experienced through carry-up of light materials from the hopper doors, smokeouts on the upper floors, and clogging of chutes. The causes of and remedies for these troubles should be further investigated; the problems are a function of such items as gas velocities and temperatures, flue size, smoothness, and tightness.

c. Controls

There is no doubt that the combustion system should be automatically controlled. The burner control can utilize either a sensing element located in the chamber or a timing mechanism integrated with the waste-burning cycle, or both.

Flame safety devices should also be incorporated. These should be of the intermittent-pilot type that must prove itself for each firing cycle; continuous pilots have caused many nuisance shutdowns due to blowout from the variable draft conditions.

5. Dust Control Equipment

The Committee concludes that the major effort for control of effluents from incinerators should be concentrated on the combustion chamber; however, dust control equipment must be provided to remove particulates from the flue gas and to ensure meeting the proposed more restrictive particulate performance criteria.

a. Separation

Separation (settling) chambers have been used to provide an area where the heavier particles may be separated from the gas stream.

These chambers have been located both in the basement and on the roof. Roof chambers have been successful in removing the heavier particles from the gas stream. However, they suffer from major disadvantages in the greatly increased pressure drop which can cause smokeouts at upper-level hopper doors, and in the potential for concentration of explosive gases.

b. Scrubbers

Two types of scrubber located in either the basement or roof area have been in general use: The spray type, wherein the effluents pass through a baffled spray chamber; and the intimate-contact, impingement type, wherein the effluents pass through a flooded perforated plate so that all of the gas stream makes contact with the water. Available data reveal that the spray type has not been as satisfactory as the intimate-contact type, which is capable of practically eliminating particulate effluents and materially reducing gaseous effluents. A basement-located scrubber cools the flue gases and reduces the amount of natural draft available. Also, water vapor may condense on the inside of the flue, and, in combination with gaseous effluents, cause corrosion. However, the advantage of a basement location is that it is likely to receive better maintenance as a result of more frequent visits from the operator; this is a serious consideration in view of the finding that lack of adequate maintenance is the principal problem with all dust control equipment.

c. Electrostatic precipitators

Electrostatic precipitators have been used for a number of years in large industrial and commercial process installations. In most electrical-production power plants, large amounts of fly ash are collected by these precipitators, constituting a disposal problem.

Recently, the electrostatic precipitator has been studied and investigated for application to the flue-fed incinerator. A test installation, operating in New York City under the manufacturer's direct supervision since March, 1962, has produced results that were satisfactory when measured visually.

d. Bag filter and cyclonic separators

Bag filter and cyclonic separators have been shown to be susceptible to rapid clogging and high maintenance requirements. Dust collectors utilizing the centrifugal principle do not lend themselves to use with flue-fed incinerators, because of the low density of the particles, failure to remove condensible gases, and other troubles, plus rapid agglomeration of combustible materials.

e. Spark arrestors

Spark arrestors, with which all incinerators should be equipped, are located on the outlet of the chimney or flue to prevent accidental release of large burning particles which could create a fire hazard. It has been found that the ideal material for construction of these devices is stainless steel. Its free-flow area between the performations should be equal to or greater than the cross-sectional area of the chimney.

6. Other Considerations

a. Smokeout problem and chimney outlets

One of the most serious problems facing the user of a flue-fed incinerator is odor emission, resulting from escape of noxious gases through hopper doors, because of either naturally existing or artificially created pressure differences.

Odor emission occurs primarily when lower pressure exists within the structure than in the flue, causing smokeout. This condition may be aggravated by exhaust fans in the corridors, restrictions in the flue, roof separation (settling) chambers, accelerated burning rates, or wind conditions. In selecting the building ventilation system, due consideration should be given to all these conditions.

Artificial pressure differences are primarily due to improper corridor ventilation. In many cases, air is exhausted so that corridors are under a negative pressure. Since most hopper doors open to the corridors, a smokeout condition cannot be avoided. Possible solutions are to avoid exhausting of corridors, and to interlock the exhaust fan with the incinerator so that the fan does not run when the incinerator is burning.

If corridor ventilation is required, it is recommended that it be attained by forced and induced ventilation. The fresh air used can be preheated so that objectionable cold air will not be circulated. Although this system is more expensive than the exhausting process, it will do much to mitigate the smokeout problem which is becoming increasingly serious in high-rise buildings. However, it should be noted that positive pressures can be a hazard in event of a fire, which would be transmitted to adjacent dwelling units.

Many problems of smokeout have been corrected by the proper location and height of the chimney outlet. The upper stories of buildings using flue-fed incinerators have always been potential areas of smokeout. The pressure differential between outside and inside of the exhaust flue is close to nonexistent, and any change in operating characteristics will cause smokeout. It is important that the flue outlets be as high as possible above the roof level, with a minimum height differential of 10 feet. A concurrent problem is the location of higher buildings or other roof structures in close proximity to the outlet; such blockages will affect the proper operation of the flue outlet.

b. Fire hazards

There is always the danger of accidental fires in the charging flues producing superheated gases, smoke, and flames which can ignite the upper stories of the building. Fire safety experts have suggested the use of sprinkler heads located at the upper flue levels to combat this danger.

Fire protection is a vital part of the design of any buildings; installing a flue-fed incinerator increases the degree of fire risk. The National Fire Protection Association (N.F.P.A.) publishes a booklet on incinerators that is applicable.

7. Operation and Maintenance

The old flue-fed incinerator consisting of a single combustion chamber and a flue required little or no maintenance. The operator simply lit the fire and periodically agitated the burning bed. These operational conditions resulted in maximum production of air pollutants--a situation now regarded as totally unsatisfactory. Modern design must take into account the contribution of operating and maintenance functions to total satisfactory performance.

a. Operator attendance

Modifying the simple flue-fed incinerator to provide some measure of automatic operation, as recommended in this report, will still require careful operator attendance if pollutant emissions are to be reduced. The addition of an auxiliary burner will improve combustion characteristics. In most cases where a gas burner is used, manual, semi-automatic, or automatic operation is possible.

Manual operation requires that the operator light and prove a safety pilot, and operate the main burner. If an overfire air system is installed (as is usual), it must also be energized. Although these operations are not difficult, an untrained operator can negate the advantages by adjusting the burner to produce a short flame rather than a luminous bushy flame; or he can fail to energize the overfire air system, so that improper combustion occurs. Therefore, a specific set of operating instructions should be posted close to the burner assembly.

Semi-automatic operation entails use of a main gas burner, electric-ignition safety pilot, overfire air, and time-clock firing control. The operator normally energizes the safety and main burners, which automatically energize the overfire air system. The time clock automatically turns on the burner assembly to fire for a predetermined period.

Automatic operation involves a main burner, electric-ignition safety pilot, overfire air system, temperature-sensing device, clock control, automatic hopper door locks, and, in the case of a by-pass flue design, hydraulically operated main flue gate. In this procedure, loading of the incinerator by the tenants is controlled by hopper door locks which prevent opening of the doors during the firing cycle. At the predetermined time, the locks are closed, the safety and main burner are energized, the flue gate (if installed) is shut, the overfire air system is energized, the by-pass flue (if installed) is opened, and the incinerator charge is burned. This system requires a minimum of operator assistance as far as combustion control is concerned. Recently, one city has been successful in reducing malfunctions of incinerators by cycling the operation so that the flue gate is normally closed and opened only for a one-minute period before the burning cycle. This permits the refuse to collect on top of the gate between starts of the burning cycle. The burning must be frequent enough, during periods of heavy charging through the hoppers, to prevent an excessive accumulation on top of the flue gate.

The major drawback is that tenants, not used to the inconvenience of waiting for the hopper doors to be operational, will block doors open, break the locks, or in some manner make the hopper door lock system inoperational. Since the whole operation is based on a series checking circuit, wherein any one malfunctioning part will prevent burner startup, it becomes necessary for the operator to go through the building to determine the status of the door locks. A detailed explanation and educational campaign for the tenants is therefore required to mitigate nuisance shutdowns. An effective dust control system, continuously operated, mitigates the need for a hopper door lock system.

The success of automatic operation is recognized by most code authorities in the fact that extended hours of operation are permitted--so that, in effect, a smaller-size incinerator can be utilized.

b. Dust collection equipment

Most of the devices used for dust control, such as settling chambers, wet scrubbers, and gas scrubbers, depend almost entirely on proper maintenance for successful operation. Settling chambers,utilizing the principle of gravity deposition, must not be allowed to accumulate the collected fly ash; accumulation will begin to reduce the cross-sectional area of the chamber, increase gas velocity, and reduce chamber effectiveness. Chambers should be cleaned at least once per week. Roof separation (settling) chambers present a problem in the disposal of the collected fly ash; in one instance it was found that the operator was dumping the material back down the flue, while another was flushing the material down the drain.

Wet scrubbers of the water-spray type, although inefficient, collect a large amount of material, which is generally flushed out. Maintenance is required to keep the spray nozzles clean, to prevent excessive sludging of the water, and to control corrosion.

Wet scrubbers of the intimate-contact type require careful maintenance. The perforated pan must be carefully watched to prevent clogging of the perforation, the strainer material above the pan must be cleared, and the sludge tank should be scrubbed down to prevent accumulation and blockage. This procedure should be carried out at least once per week. It has been found that continuous operation of scrubbers gives the most satisfactory means of controlling emissions when active burning is completed but smoldering continues.

8. Summary

In summary, the Committee feels that the effort toward improving the performance of incinerators should be threefold:

1. Most important, to improve the firing process, to consume refuse more completely, and so to minimize generation of air pollutants.

2. To remove from the gas stream, before discharge into the air, as much as practicable of fly ash and other pollutants.

3. To locate the discharge point in such fashion that residual pollution would cause the least damage and discomfort.

The first goal may best be achieved through provision of an adequately and properly designed system, including automatic combustion controls, clock controls, overfire air system, auxiliary burners, etc.

Dust and fly-ash control may be provided through the use of scrubbers, precipitation, etc.

Finally, the discharge flue should terminate at a point high enough above the ground and far enough away from receptors to avoid nuisance. The flue should terminate with an approved spark arrestor.

APPENDIX A

Listing of

GROUPS AND INDIVIDUALS KNOWN TO SPECIALIZE IN INCINERATOR TESTING AND/OR RESEARCH

Battelle Memorial Institute 505 King Avenue Columbus, Ohio	R. B. Engdahl
Harvard School of Public Health 55 Shattuck Street Boston, Massachusetts	R. Dennis
Hemeon Associates 121 Meyran Avenue Pittsburgh, Pennsylvania	W. C. L. Hemeon
Illinois Institute of Technology Research Institute Technology Center Chicago, Illinois	A. Lieberman
William T. Ingram 7 North Drive Whitestone, N. Y.	W. T. Ingram
New York University Research Division University Heights New York, N. Y.	E. R. Kaiser
Wisconsin Chemical and Testing Company 2721 North 97th Street Milwaukee, Wisconsin	F. R. Rehm

APPENDIX B

TECHNICAL LIAISON

A technical liaison group representing the Housing and Home Finance Agency and the General Services Administration gave freely of their time and advice for the successful culmination of this study. Members of this group are:

ORVILLE BAUBLITZ, Mechanical Engineer, Design Services Branch, Public Housing Administration, Housing and Home Finance Agency, Washington, D. C.

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