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TECHNOLOGY FOR USE OF INCINERATOR RESIDUE AS HIGHWAY MATERIAL

Identification of Incinerator Practices and Residue Sources

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Interim Report

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16. Abstract

A survey was made of present municipal incineration practices in the United States and other countries. Previous world-wide research and development work on the use of incinerator residues as highway material is summarized. The types, quantities, and locations of municipal incinerator residues produced in this country were determined. The predominant factors affecting residue quality are the nature of the burning action and the degree of burn-out. Six basic types of incinerator residues were identified according to a classification system based on incinerator design. At the present time there are 141 incinerator plants and one pyrolysis plant in operation in 22 states plus the District of Columbia. Most of these plants are located in the northeastern states. These plants produce approximately 5.5 million tons of residue per year. Well burned out residue types 1 and 2 comprise 25 percent of the residue total. The incinerator residues available in the United States could supply from 1 to 9 percent of the annual highway aggregate requirements of the states in which the incinerators are located.

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1. INTRODUCTION

Incineration has become the principal method for municipal refuse disposal in practically all large cities throughout the world. It is used because it quickly reduces the volume of heavy, wet, bulky refuse by a substantial amount right at the point of its generation. This eliminates the need for massive hauling and land filling. Bulky articles such as boxes and packaging materials are reduced in size and weight without a great expenditure of time, energy and labor. Disposal of the resulting incinerator residues, which are only 3 to 20 percent of the initial refuse volume, is considerably more economical in terms of hauling and landfill requirements than refuse hauling and landfilling. There are many other reasons for the selection of incineration for solid waste management in populous cities, among these are vermin, odor, and fire hazard elimination plus the high degree of sterilization that is achievable. Metals recovery is also simplified by incineration since adhering paper and plastics are stripped from their surfaces. The easily compacted incinerator residues produced are also less leachable and have substantially lower gas forming tendencies than raw refuse.

Incinerator construction began in this country at the end of the nineteenth century and gradually proliferated for the next fifty years. A significant upsurge in the number of incinerators then took place following World War II. Most incinerators built were small 100 - 200 ton/day, batch operated units, which were built as needed and distributed around the municipalities that they served. While wide distribution of small incinerators initially reduced collection distances and costs, it is now gradually contributing to the technical and economic obsolescence of many of these plants. Installation of necessary air and water pollution control systems at small plants can not be justified economically. The trend which began in the late 60's and is now fully underway is the contruction of large centrally operated incinerators.

Greater overall efficiency and economy of scale is realized in the newer large plants. Most of the new plants are at least ten times bigger than older plants (for example, Chicago's new Northwest incinerator has a capacity of 1600 tons/day). Much attention has been given to selective materials recovery and some form of energy recovery in all of the new plants. A lesser amount of attention has been given to residue disposal in these plants, possibly because the problem has been reduced. Better burn-out as a result of continuous operation and better grate design produces less residue. In most of the big new plants (including Baltimore's 1,000 ton/day pyrolysis unit) some form of highway construction useage of the residues is being sought.

This survey on incinerator practices and incinerator residues (Task A) was part of a larger study undertaken for the purposes of establishing how and to what extent incinerator and pyrolysis residues could be used in highway construction, using a minimum of processing.

2. OBJECTIVES

The objectives of the Task A study were to survey municipal incineration practices in the United States, in order to define the types, quantities, and locations of incinerator residues produced and to review previous world wide research and development work on the use of incinerator residues in highway projects.

3. RESEARCH APPROACH

The literature review of municipal incineration practices and useage of incinerator residues in highway construction was conducted using three major information sources.

1. A machine and manual search of the solid waste literature was made using EPA's Solid Waste Information Retrieval System (SWIRS). Key words covering incineration, residues, aggregates and highway construction were used in the search.

2. A review was made of conference proceedings and other general library sources of information on incineration and incinerator residues.

3. Personal contacts by members of the research team uncovered numerous other pieces of useful information. Personnel of the U. S. Environmental Protection Agency, various city and municipal governments, and private companies that were contacted provided a substantial amount of this pertinent data.

The survey on presently operating U. S. incinerators (for establishment of types, quantities and locations of residues) began by discussions with U. S. Environmental Protection Agency personnel. Mr. Donald Oberacker, EPA, Office of Solid Waste Management, Cincinnati, Ohio indicated that Mr. Richard Fenton, Assistant Administrator of the NYC Environmental Protection Administration, was in the process of directing an incinerator survey, which included some of the data necessary for this present study. Fenton's study was in part supported by the American Society of Mechanical Engineers. Examination of Fenton's questionnaire revealed that all the data necessary for this Task A study could be obtained by combining his survey data on presently operating plants and their current capacities with technical data on these plants contained in two past incinerator surveys (annotated bibliography section 4.1 references 13 and 20).

4. ANNOTATED BIBLIOGRAPHIES

The following annotated bibliography covers references on (1) municipal incinerator practices and trends with specific emphasis on the types and characteristics of residues produced from different types of incinerators and (2) a review of previous works on the use of incinerator residues in highway construction.

4.1 ANNOTATED BIBLIOGRAPHY ON MUNICIPAL INCINERATOR PRACTICES AND TRENDS

1. Achinger, W. C. and Baker, R. L., *Environmental Assessment of Municipal Scale Incinerators,* (SW-111), U. S. Environmental Protection Agency, 1973. 31p.

   The status of incineration plants in the U. S. is covered through May, 1972. At that time, 193 plants were operating with a combined total design capacity of 70,667 tons of refuse per day. In the three years between 1969 and 1972, a total of 58 small obsolete incinerators were shut down. This represented a capacity decrese of only 9,000 tons per day.

   Approximately 75 percent (viz. 153 of 193) of the incinerators in the U. S. are located in the northeastern quarter of the country. Approximately 50 percent (90 of 193) are located in an *incinerator belt* between Washington, D. C. and Boston.

   It was concluded that municipal-scale incinerators should not have a negative environmental impact if they;

   a. are equipped with proper air pollution control devices
   b. treat their wastewaters
   c. dispose of their residue in a sanitary landfill
   d. adhere to a litter control program.

2. Achinger, W. C. and Daniels, L. E., *An Evaluation of Seven Incinerators*. In Proceedings; 1970 National Incinerator Conference. American Society of Mechanical Engineers, New York 1970. p. 32 - 64.

   An evaluation of the performance of seven different incinerator designs was carried out. The qualities and quantities of refuse were studied, along with the character of the residues, quench-

waters, and gaseous outputs. Economic as well as operating performances were analyzed. Volume reductions of 94 to 99 percent of the incoming refuse were found. Unburned combustibles ranged from 0.1 to 36 percent; the low values coming from rotary kiln incinerators. Forty to fifty percent of the residue material was under one-half inch for all batch and continuous designs, except for the rotary incinerators. In the latter, 75 to 80 percent of the residue was finer than one-half inch as a result of the vigorous tumbling action.

3. Bielski, E. T. and Ellenberger, A. C. J., *Landgard for Solid Wastes*. In Proceedings; 1974 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1974. p331-336.

A description is given of the Monsanto Enviro-Chem Systems, Inc. 1,000 ton/day pyrolysis unit installed at Baltimore. Physical properties of the pyrolysis residue are given. The operation consists of shredding, pyrolysis at 1500 - 2,000°F (820 - 1,090°C), and resource recovery of ferrous metals, glassy aggregate, carbon and waste heat. Waste heat recovery via steam generation for production of electricity is planned. Glassy aggregate will be used with asphalt in street paving. The City of Baltimore reportedly uses quantities of aggregate sufficient to consume all of the glassy aggregate from this plant.

4. Bowen, I. G., and Brealey, L. *Incinerator Ash-Criteria of Performance*. In Proceedings; 1968 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1970. p.18 - 22.

A study of unburnt materials from various incinerators was made. Comparisons with various coal fired furnace designs were given. Two tests for unburned carbon were used; a straight air oxidation and a chemical digestion. It was concluded that for stoker grates burning coal and refuse, the refuse burn-out was much better than coal burn-out.

5. Colonna, R. A. and Cynthia McLaren. *Decision-Makers Guide in Solid Waste Management*. (SW-127) U. S. Environmental Protection Agency 1974. 157p.

This review covers aspects of solid waste disposal from collection through recycling and sanitary landfilling. An update on the status and trends of incineration is given in the chapter on *Energy Recovery and Thermal Reduction*.

Conventional refractory lined incinerator designs as used in the past now have been almost totally eliminated from consideration in new plants. They depend on the use of excess air (ca. 300 percent) to carry off the heat of combustion. This results in large expensive furnaces and very large, expensive, and not very effective air pollution control devices. *Waterwall* incinerators which pick-up the waste heat by radiative transfer have come into use. Steam and/or electricity are a potential by-product of these incinerators, as well as the incinerator residue. The smaller quantity of gases coming from these units enables economical and efficient air pollution control.

Pyrolysis units are also replacing old-fashioned refractory lined incinerators. These units operating at 1,000 to 2,000°F (538 to 1,093°C) without the introduction of any air cause the breakdown of organic wastes into liquid and gaseous compounds usable as fuels. Both water-walled incinerators and pyrolysis units leave residues of inorganics and unburned char which can be put through recovery processes for separation of metallics and glass.

6. Corey, R. C., *Principles and Practices of Incineration*. Wiley-Interscience, New York, 1969. 297p.

Municipal, commercial, and industrial incineration are covered in this book. Fundamental principles and data as well as design methods and practices are discussed. However, very little coverage is given to residue characteristics or disposal.

7. Jensen, M. E. *Observations of Continental European Solid Waste Management Practices*. Public Health Service Publication No. 1880 U. S. Department of Health, Education and Welfare; Bureau of Solid Waste Management, 1969.

An excellent review of European solid waste management practices is made. This includes discussions and technical comparisons with U. S. practices. All German cities with populations greater than 50,000 use incineration or composting. Smaller cities take part in regional systems. A key point made by Jensen is that European incineration systems are largely based on optimum design rather than a minimum cost principle. This extends to residue disposal systems as well. *Many plants included equipment to process incinerator residue for use in road subbases, path and trail construction, or as aggregate in concrete construction.* Crushing, electromagnetic removal of iron, and screening to the desired gradation were basic process steps used. Jensen doubted whether the extra processing costs could be justified on a direct comparison with natural materials alone.

Population density is singled out as the most important factor justifying the technologies used in European waste disposal. For example, Munich has long utilized a heat recovery incineration system. (Coal is burned with the refuse). The clustering of high rise multiple dwelling apartments in that city utilize the heat. Heat recovery from the burning refuse rather than dilution of the hot gases with cooling air also enables using the very high efficiency air pollution control methods that are required with high population density. Dilution of hot gases with cooling air has been commonly used in the United States.

8. Kaiser, E. R., and McCaffery, J. B., *Municipal Incinerator Refuse and Residue*. In Proceedings; 1968 National Incinerator Conference, American Society of Mechanical Engineers, New York, 1970, p.142 - 153.

   Physical characteristics of municipal refuse and incinerator residues were studied. Variations in residue density, moisture and carbon contents, and composition were noted. Screening of the residues through one-quarter inch and ten mesh screens was carried out prior to analysis. ASTM fusion temperatures were measured on the residue components. Glass components proved to have the lowest fusion temperatures (1480°F, 805°C).

9. Kaiser, E. R., Zimmer, C., and Kasner, D. *Sampling and Analysis of Solid Incinerator Refuse and Residue*. In Proceedings; 1970 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1970. p.25 - 31.

   Physical and chemical analysis data were obtained on municipal refuse and incinerator residue including bulk density, moisture, carbon, hydrogen, oxygen, nitrogen, sulfur, chlorine, inerts and calorific values.

10. Kaiser, E. R. *Chemical Analysis of Refuse Components*. In Proceedings; 1966 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1966. p.84 - 88.

    A detailed examination of the proximate and ultimate analysis of 20 major constituents of municipal and commercial refuse was made along with their calorific values. These ranged from newspapers, brown paper, and magazines to fried fats, and ripe tree leaves. From this information an understanding of the burning characteristics of these components was obtained along with useful design information for heat and material balances, air requirements and exhaust gas volumes.

11. Kenahan, C. B.; Sullivan, P. M.; Ruppert, J. A.; and Spano, E. R., *Composition and Characteristics of Municipal Incinerator Residues,* RI-7204 Bureau of Mines, U. S. Department of Interior. Dec. 1968. 19p.

The composition and physical characteristics of residues from five types of batch and continuous incinerators were analyzed. Sample residues were screened into three cuts using 2 and 8 mesh screens. The coarsest cuts were mainly cans, massive iron pieces, bricks and stones, with unburned paper and some large glass pieces. The 2 - 8 mesh cuts were mainly glass. The minus 8 mesh cuts were oxides and silicates of iron, aluminum, copper, lead, manganese, nickel, tin, zinc, titanium and magnesium. The chemical composition for residues from each incinerator was about the same, except for the carbon and moisture content. Glass constituted 44 percent and metallics 30 percent of the average residue weight. Unburned carbon varied from 3 to 12 percent. Moisture ranged from 24 to 30 percent.

12. Matsumoto, K.; Asukata, R.; and Kawashima, T. *The Practice of Refuse Incineration in Japan of Refuse with High Moisture Content and Low Calorific Value.* In Proceedings; 1968 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1968. p180 - 195.

An interesting comparison of differences between incineration in Japan and in the U. S. and Europe is given. The principal differences with Japanese practices are attributable to:

1. a very high moisture content in their refuse (viz. 40 - 70 percent vs. 10 - 45 percent for U. S. and European refuse)

2. a very low paper content (viz. 24 percent vs. 42 percent in in the U. S.).

These factors arise from differences in food processing, methods of cooking and the lack of garbage disposal units in Japan. The lower heating value of Japanese refuse is 500 - 1300 cal/gm (900 - 2,340 BTU/lb.) vs 1,000 - 2,500 cal/gm (1,800 - 4,500 BTU/lb.) for U. S. and European refuse. Japanese incinerators always require supplementary fuel for normal operation. Unburned combustibles in the residue are kept below 10 percent by law. The Japanese Government launched a 5 year crash program in 1967 to provide 1,273 cities with incinerators capable of burning 22 million tons of refuse per year..

13. Niessen, W. R. *Systems Study of Air Pollution From Municipal Incineration*. Under Contract CPA-22-69-23. U. S. Department of Health, Education, and Welfare, March 1970. Two Volumes.

A review of all operating U. S. incinerators was carried out. This covered design details, operating features and experience including economic factors, and corresponding air pollution problems and methods of control. Recommendations for air pollution control were made based on an analysis of present operating experiences and future trends.

14. Niessen, W. R. and Chansky, S. H. *The Nature of Refuse*. In Proceedings; 1970 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1970. p. 1 - 24.

The nature of solid waste was defined and projected through the year 2000. Changes in waste composition through that period should be beneficial to the disposal problem. Refuse bulk density should decrease and heating value should increase in that period. A 270 percent increase in solid waste load should occur by the year 2000.

15. Rogus, C. A., *An Appraisal of Refuse Incineration in Western Europe*. In Proceedings; 1966 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1966. p. 114 - 123.

A description of the state-of-the-art of incineration found in European practice is covered. Thirteen plants, of different designs, in seven countries are described. Design performance and mode of operation are analyzed. Better burn-outs and cleaner plants and surrounding environments were found, in general, compared with U. S. operations; this is attributable to better designs and more careful attention to operating control.

16. Rousseau, H. *The Large Plants for Incineration of Domestic Refuse in the Paris Metropolitan Area*. In Proceedings; 1968 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1968. p. 225 - 231.

Four large incinerator plants service the Paris area. All are connected to the railway system for residue haulage to landfills. Residue from the St. Oven plant reportedly is generally sold for highway construction and ferrous content is extracted when economic conditions are favorable. Steam generation, salvage operations and modern automated control characterize these plants.

17. Schoenberger, R. J. and Purdom, P. W. *Classification of Incinerator Residue*. In Proceedings; 1968 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1968. p. 237 - 241.

The water soluble fraction of refuse and incinerator residue were examined from different incinerators. Leachability and the pollution potential of the residues was of interest. The pH, alkalinity, nitrate, phosphate, chloride, sulfate, iron, sodium and potassium were measured. Approximately 4 - 5 percent of the residues were soluble.

18. Schoenberger, R. J.; Trieff, N. M.; and Purdom, P. W. *Special Techniques for Analyzing Solid Waste or Incinerated Residue*. In Proceedings; 1968 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1968. p. 242 - 248.

The analysis of chemical constituents in incinerator residues and refuse was carried out. Analytical methods were compared for residual carbon, nitrogen, hydrogen, protein, chemically decomposable organics and calorific values.

19. Stabenow, George. *Performance of the New Chicago Northwest Incinerator*. In Proceedings; 1972 Incinerator Conference. American Society of Mechanical Engineers, New York, 1972. p. 178 - 194.

A description of the design features and operational performance of Chicago's 1,600 tons/day steam generating incinerator is given. Good burn-out, energy recovery and excellent air pollution control are reported. The installation marks a new trend as far as U. S. solid waste handling is concerned. However, good burn-out, energy recovery and complete pollution control have been commonplace in Europe for some time.

20. Stephenson, J. W. and Cafierro, A. S. *Municipal Incinerator Practices and Trends*. In Proceedings; 1966 National Incinerator Conference, American Society of Mechanical Engineers, New York, 1966. p. 1 - 38.

Detailed data on 290 incinerators designed or built in the U. S. and Canada between 1945 and 1966 was compiled from questionnaires. Design and operational features were catalogued including residue disposition. Emphasis was placed on surveying and analyzing operating capacity, performance, and trends.

21. Wegman, Leonard S., and Company, *Marketability of Recovered and Classified Incinerator Residues in the New York Metropolitan Area*.

Environmental Protection Agency Publication, EPA 530/SW-42C-73-008 (distributed as PB-222-588 by National Technical Information Service, Springfield, Va. 1973, 188p.)

A detailed marketing study was conducted for potentially recoverable components from incinerator residues in the New York City vicinity. The U. S. Bureau of Mines separation scheme was used as the model. Income and operating costs for a 150 ton/day residue recovery plant located at North Hempstead, Long Island, were calculated, including delivery costs. Ferrous, non-ferrous, glass, and *sand-ash* fractions were the product fractions considered. It was concluded that *the sand recovered from the residue has some potential for use ... as fine aggregate in pavement.* Tests on the sand were planned by the North Hempstead N. Y., Department of Highways.

It was felt that *the ready availability of natural aggregates ... tends to severely limit the potential for marketing this component.*

22. Zinn, R. E.; LaMantia, C. R.; and Niessen, W. R. *Total Incineration.* In Proceedings; 1970 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1970. p. 116 - 127.

Seven different processes are reviewed which reduce refuse to a burned-out fused slag plus flue gases. All require supplementary fuel or pure oxygen to produce temperatures in excess of 3,000°F (1650°C) which totally burn out and fuse the residues. A 97 percent reduction in volume is achieved in all processes. Problem areas resulting from the 3,000°F plus temperatures discussed are:

1. high NOx production (viz. 1,000 percent more NOx than in conventional incineration)

2. high fuel costs

3. high equipment maintenance cost

4. operational complexity

5. operational safety

4.2 ANNOTATED BIBLIOGRAPHY ON HIGHWAY USES OF INCINERATOR RESIDUES

At the present time, there has been a limited use of incinerator residues for highway purposes in the United States. European practice appears more widespread, judging from citations in the literature. However, details of the practices are not reported in the solid waste, highway or construction literature. Each user apparently develops suitable procedures for use. In addition, there are indications that incinerator residues may be used in highway construction on a sporadic basis, rather than continuously. Useage consistent with major construction projects may be a reason for this practice.

The same situation to some extent may apply to U. S. practices. During World War II, motivated by shortages and economics, incinerator residue was used as subbase and embankment material in the construction of Pennsylvania Highway 291 *(The Industrial Highway)*. The residue was also widely used at that time for embankment construction of numerous fire dams around the oil tanks of the several large refineries in Philadelphia. Mr. Dominick Cappelli of Cappelli Brothers Trucking, Glen Mills, Pennsylvania whose firm carried out much of this construction, reports that the material was an excellent construction material, but that the practice was stopped after the war.

Similar reports of highly successful but non-continuous useage of incinerator residue in road construction come from New York City. Mr. Richard Fenton, presently Assistant Commissioner New York City Environmental Protection Administration reports that both refuse and incinerator residue were used in constructing many streets in Brooklyn during and after World War II. No detailed studies, reports, or publications on the practice were made. However, the residue was a superior subgrade material. It compacted readily, whereas refuse used as fill in construction produced a spongier support. The following paragraphs describe the results of recent known research and development work on highway related application of incinerator residues.

1. *Personal Communication. Collins, Robert J. with* Conatty, *Norman, Sanitation Department, Tampa, Florida.*

   During the past few years the City of Tampa, Florida, has been using the residue from a rotary kiln incinerator as fill or embankment material, soil stabilizer, and as subbase for parking lots. The City normally stockpiles the residue for approximately a year, during which time oxidation of cans and decomposition of combustibles takes place. This stockpiling equivalent to an extended burn-out has resulted in improving the gradation, stability, and compaction characteristics of the residue.

   The City uses the stockpiled residue without any stabilizer (such as lime or cement) and has achieved very satisfactory density results when placing the material in twelve-inch lifts, grading the lifts, and rolling with a standard steel-wheeled roller. Some Proctor tests have been performed in the laboratory and in-place density tests performed in the field, but no test results are presently available.

   There are several examples of the use of rotary kiln residue in highway construction in and around the Tampa area. A portion of low lying, swampy area was filled with this residue to a thickness of between three and four feet and stabilized to allow for a two-block extension of McDale Avenue in Tampa. A haul road in neighboring Hillsboro County was stabilized by placing and rolling incinerator residue as a subbase.

   Two parking lots were constructed over a base of compacted incinerator residue. After placing and rolling the residue at three projects, the base course was protected from dusting by sealing the residue with tack coat material.

   Although some cans were present in the residue at the time of its placement in the parking lots, corings taken after two years in service indicate that the cans have almost completely decomposed. At the present time, cans are not magnetically separated, but the City of Tampa expects to begin separation of cans from residue at the incinerator plant sometime in the near future.

2. *Personal Communication. Collins, Robert J. with Gnaedinger, John, President, Soil Testing Services, North Brook, Illinois. September 11, 1974.*

Research sponsored by the Federal Highway Administration with Soil Testing Services of Northbrook, Illinois, is aimed at promoting the use of lime-treated incinerator residue in base course construction. Lime-treated incinerator residues or "Chempac"[1] have been extensively studied by Soil Testing Services and numerous test installations have been made. Their work for the Federal Highway Administration involves further testing and evaluation of lime - incinerator residue mixtures under well controlled conditions.

Laboratory test results obtained from Soil Testing Services for incinerator residues used in lime - incinerator residue compositions are indicated in Tables 1 and 2. Table 3 summarizes results of tests conducted on several Chempac compositions. Values from the California bearing ratio (CBR) test ranged from 62 to 111, which compare favorably with published CBR values for gravel and crushed stone (Figure 1).

An experimental installation of lime-treated incinerator residue was placed during October of 1974 as the base course of a parking lot (30ft by 150ft), together with an access road and a gasoline pump island, for the Bell Edison Company in Chicago, Illinois. The incinerator residue used in this installation was obtained from a privately owned incinerator at 38th and Laramie Streets in Chicago, Illinois. The base course composition contained 8 percent by weight of waste calcium oxide obtained as a by-product in the manufacture of lime.

3. *Personal Communication. Collins, Robert J. with Professor Koerner, Robert, Drexel University, Philadelphia, Pennsylvania. November 15, 1974.*

There has also been some laboratory testing of incinerator residues for use in Portland cement concrete. This research was performed at Drexel University in Philadelphia for the purpose of determining the potential of using incinerator residue as a component of Ferro-cement mixtures in canoe construction. This work initially involved sampling of incinerator residue from the Northwest Incinerator in Philadelphia and determining the physical properties of this residue. The residue was screened through a one-half inch sieve and the material passing this sieve was tested for its

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1/ *J. P. Gnaedinger, Material and Method for Pavement Construction, U. S. Patent 3,293,999 (December 27, 1966).*

TABLE 1
SIEVE ANALYSIS* OF
INCINERATOR RESIDUE SAMPLES
USED IN CHEMPAC COMPOSITIONS

Sieve Size	Sample 1	2	3	4	5	6	7	8
1"	100	100	100	100	100	100	100	100
1/2"		95.2	95.9	91.0	99.0	96.8	99.2	
3/8"	79.7							
4	61.2	75.2	75.5	71.9	85.4	79.5	88.7	75.4
10	40.9	66.0	54.2	51.8	67.6	60.3	55.6	
20	25.1							
40	16.3	27.4	21.1	26.5	39.0	30.9	12.6	
80		16.6	5.8	15.6	26.4	18.7		
100	5.2						4.4	7.9
200	2.8	5.0	1.9	9.3	15.4	6.2	4.0	4.7

Sample	Location of Sample
#1	Cicero, Illinois - Old Stockpile
#2	Cicero, Illinois - Fresh Stockpile
#3	Cicero, Illinois - Fresh Stockpile
#4	Cicero, Illinois - Fresh Stockpile (after Carbon Burn out)
#5	Cicero, Illinois - Fresh Stockpile
#6	Cicero, Illinois - Fresh Stockpile
#7	Atlanta, Georgia
#8	Cicero, Illinois

* Percent passing

TABLE 2
Loss on Ignition
of Residue Samples Used in Chempac Compositions
(@ 1500°F for 1 Hour)

Sieve Size max size	min size	Cicero (Old Stockpile) Ignition Loss % of Total Sample	Cicero (Fresh Stockpile) Ignition Loss % of Total Sample
1"	3/8"	.4	.3
3/8"	#4	1.2	3.5
#4	#10	2.0	2.7
#10	#40	3.2	5.1
#40	#100	2.2	
#100	#200	.7	
#40	#80		4.3
#80	#200		3.6
Plus 200		.8	5.5
% of Total SAMPLE		10.5%	25.0%

TABLE 3
Summary of Laboratory
Results on Chempac Compositions

Unconfined Compression Test

Mixture #1 - 95% Residue (Miami, Florida) 5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
1 Month	168 psi to 242 psi
3 Months	342 psi to 391 psi
6 Months	410 psi to 432 psi
9 Months	343 psi to 632 psi

Mixture #2 - 95% Residue (Fresh Stockpile, Cicero, Illinois)
5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
3 Days	104 psi to 110 psi
10 Days	116 psi to 128 psi
1 Month	200 psi to 295 psi
3 Months	175 psi to 338 psi
6 Months	173 psi to 418 psi

Mixture #3 - 95% Residue (Old Stockpile, Cicero, Illinois)
5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
1 Month	181 psi to 241 psi
3 Months	308 psi to 485 psi
6 Months	353 psi to 483 psi

Mixture #4 - 93% Residue (Old Stockpile, Cicero, Illinois)
7% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
1 Month	241 psi to 290 psi
3 Months	322 psi to 332 psi
6 Months	360 psi to 448 psi

TABLE 3 - CONTINUED

Mixture #5 - 95% Residue (Atlanta, Georgia)
5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
1 Month	286 psi to 361 psi
3 Months	163 psi to 274 psi
6 Months	184 psi to 193 psi
9 Months	267 psi to 305 psi

Mixture #6 - 95% Residue (Fresh Stockpile, Cicero, Illinois)
5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (RANGE)
3 Days	82 psi to 99 psi
10 Days	112 psi to 116 psi
1 Month	92 psi to 245 psi
3 Months	83 psi to 222 psi
6 Months	288 psi to 346 psi
9 Months	287 psi to 586 psi

Mixture #7 - 95% Residue (City of Chicago)
5% Hydrated Lime

AGE	COMPRESSIVE STRENGTH (VALUES)
3 Days	76 psi to 84 psi
10 Days	116 psi to 126 psi
1 Month	196 psi to 207 psi
3 Months	254 psi to 316 psi
6 Months	425 psi to 476 psi

NOTE: The above tests were performed by Soil Testing Services, Inc., of Northbrook, Illinois, on 2" x 4" specimens cured in a moist curing room, presumably at or near 70°F.

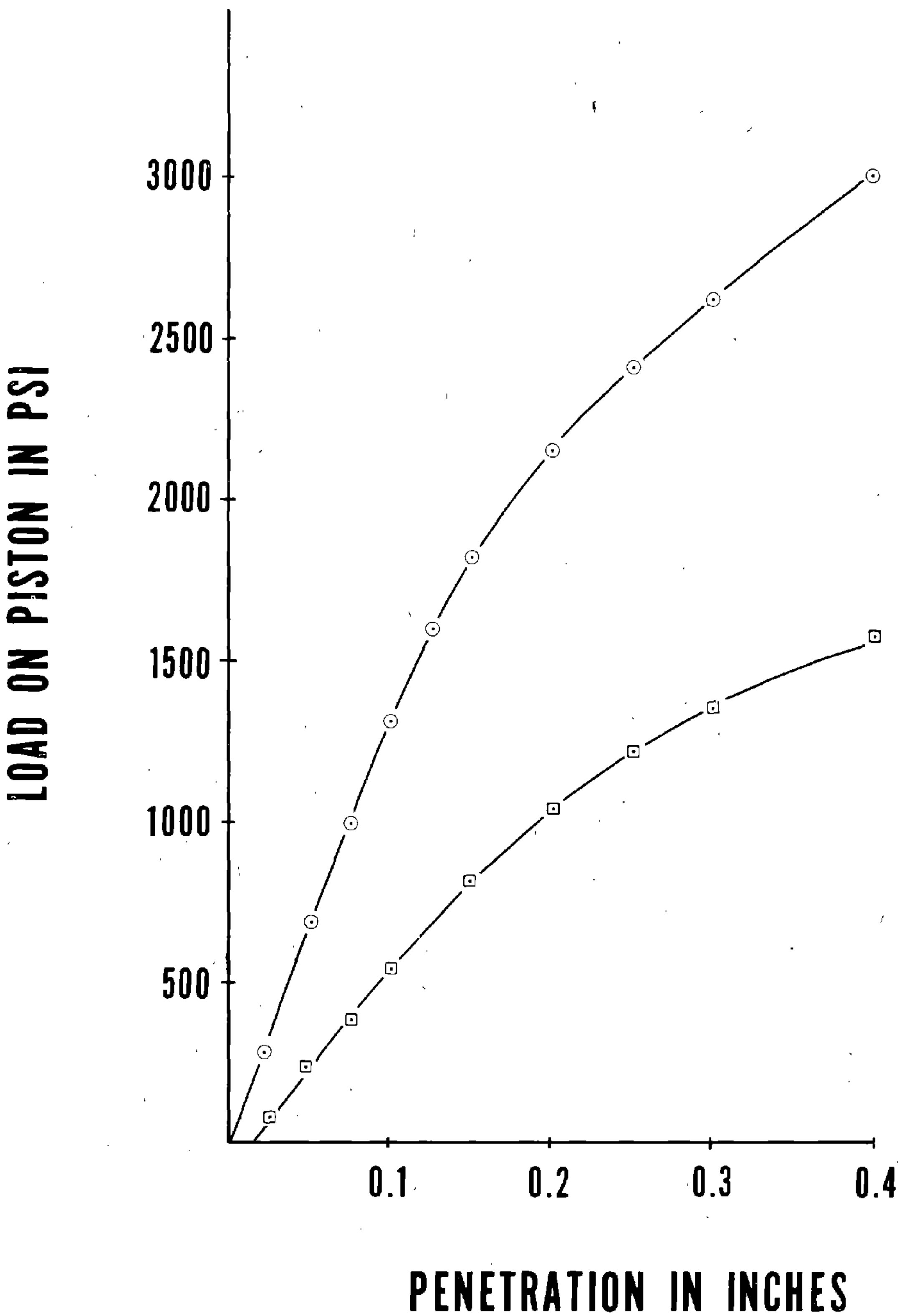

Figure 1: California Bearing Ratio of Incinerator Residue from Chicago, Illinois

gradation, dry density, specific gravity, and absorption. Table 4 presents a summary of these results.

A total of twelve different residue-cement mixes, with varying proportions of aggregate, cement, and water, were designed, molded, and tested in unconfined compression. Water-cement ratios were varied between 0.55 and 0.75, while aggregate-cement ratio of 0.5, 1.0, and 1.5 were used. Figure 2 indicates that the maximum unconfined compressive strength value attained was 1300 psi at a water-cement ratio of 0.55 and an aggregate-cement ratio of 1.0. These values represent approximately one-third of the compressive strength obtained from conventional concrete mixtures of similar proportions using sand as the aggregate. However, it must be remembered that the proportioning of these mixes was done in order to attain the needed workability for the construction of canoes.

4. *Personal Communication. Collins, Robert J. with Ledbetter, William, Texas Transportation Institute, College Station, Texas. September 25, 1974.*

Another federally-sponsored research program using incinerator residue was conducted in cooperation with Texas Transportation Institute. An experimental black base material was developed, in which incinerator residue was trommeled through a 1-inch screen and mixed with 9.5 percent asphalt (AC-20) and 2.0 percent hydrated lime. Table 5 is a summary of laboratory and field test results conducted at Texas Transportation Institute on this material, using the Marshall test procedure. These results indicate that this mixture meets or exceeds the Marshall design criteria for stability and flow of bituminous mixes.

A test section of this experimental black base was placed on several hundred feet of a four-lane access road portion of Bingle Road in Houston, Texas, during July, 1974. Wet residue from Holmes Road municipal incinerator was initially pre-treated with lime and water by means of a lime slurry treatment. The material was spread out, dried, and mixed the following day with asphalt. After mixing, the material was placed on the subgrade in two, three and one-half inch lifts, for a total compacted thickness of seven inches. The base course appears to be functioning satisfactorily up to the present time.

5. *Personal Communication. Collins, Robert J. with Wahl, Herbert, Boeing Corporation, Eddystone, Pennsylvania*

Some laboratory testing of incinerator residues from various

TABLE 4
PHYSICAL PROPERTIES OF RESIDUE
FROM PHILADELPHIA NORTHWEST INCINERATOR

1. Sieve Analysis

Sieve Size	Percent Passing
1 1/2"	100
1 "	81
1/2"	60
3/8"	53
No. 4	44
No. 8	25
No. 16	22
No. 30	17
No. 50	10
No. 100	7
No. 200	4

Note: Large pieces were removed prior to sieving.

2. Dry Density Test

Maximum dry density = 60.4 lbs./cu.ft.
Minimum dry density = 39.8 lbs./cu.ft.

3. Absorption Test

Absorption = 8.0% (ASTM Designation C128)

4. Specific Gravity

Specific Gravity = 1.62

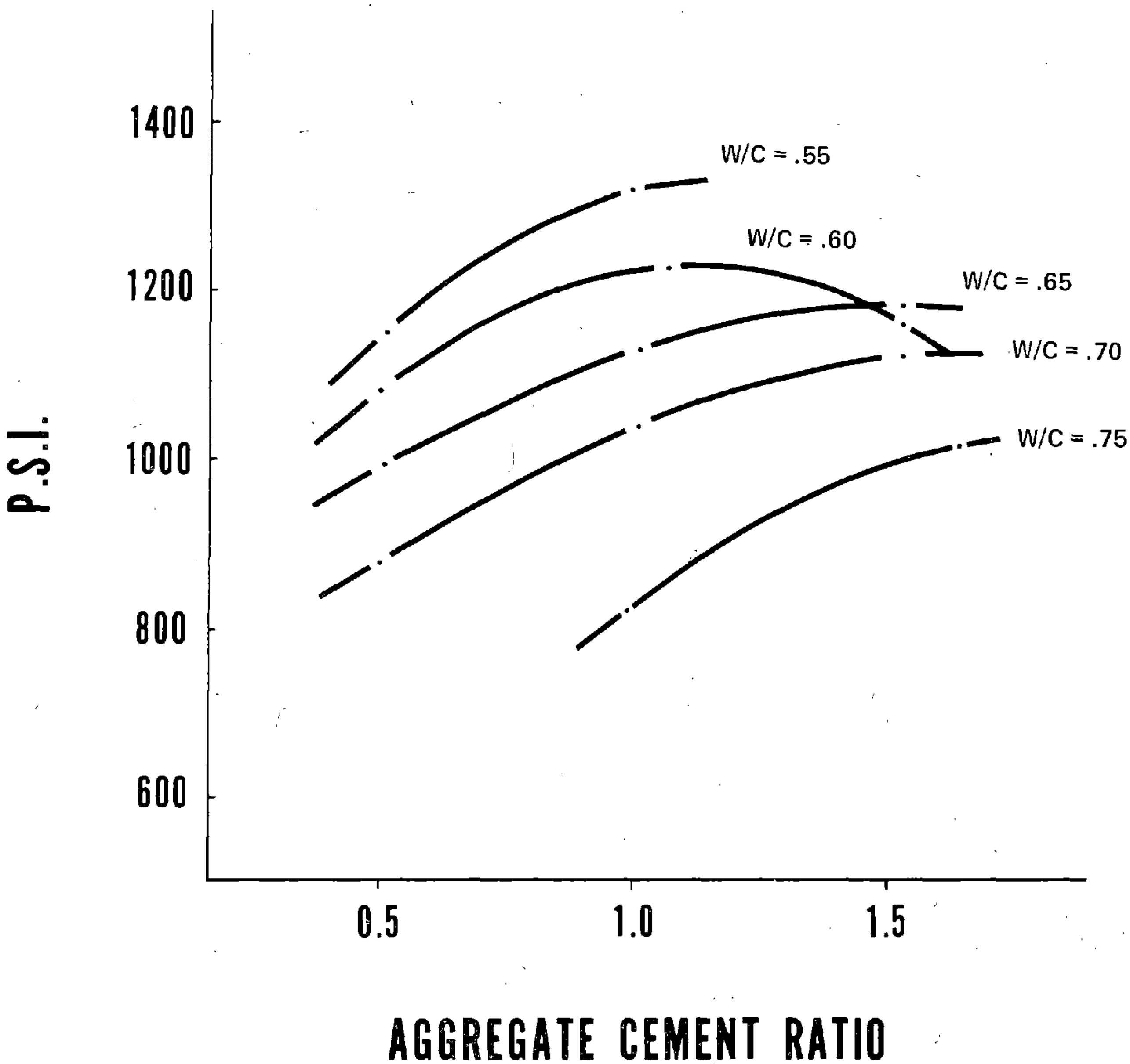

Figure 2: Compressive Strength Results
Drexel University, Philadelphia, Pa.

TABLE 5
SUMMARY OF EXPERIMENTAL BLACK BASE
LABORATORY TEST DATA FROM
TEXAS TRANSPORTATION INSTITUTE

1. Laboratory analysis of incinerator residue.

Sieve Size	Cumulative Percent Passing by Weight
1 inch	100
3/4 inch	94.7
1/2 inch	75.4
3/8 inch	54.6
No. 4	29.0
No. 80	5.5
No. 200	3.2

Loss on ignition (15 min. @ 1850°F.) 5.4 percent

2. Laboratory analysis of asphalt specimens

HVEEM Stability	30
Marshall Stability, pounds	1810
Marshall Flow, 0.1 inch	19

3. Properties of cores taken immediately after construction.

Density, lbs./cu.ft.	125
Percent air voids	6
Percent voids in mineral aggregate (VMA)	27
Percent voids filled with asphalt	69

locations for use in bituminous binder courses and base courses was done over a two to three year period by the Boeing Company. In the course of their research, Boeing concluded that incinerator residues met the gradation requirements of aggregate for use in bituminous binders in Pennsylvania. Laboratory tests were conducted to determine the aggregate properties of rotary kiln incinerator residues from Grosse Point, Michigan, and Chester, Pennsylvania. The results of these tests are summarized in Table 6. These results were compared with Pennsylvania DOT requirements and were generally found to be within specification requirements.

In addition, Marshall tests were performed on bituminous specimens molded using residue from each of the above sources with between 7.5 and 9.0 percent asphalt. Marshall test values indicate that the incinerator residues tested can be used to produce acceptable bituminous paving mixtures. Table 7 presents a summary of these Marshall test results, which are within acceptable standards of the Asphalt Institute.

6. *Personal Communication. Collins, Robert J. with Zulver, Elliott City of Baltimore, Department of Public Works, December 3, 1974.*

The City of Baltimore, Maryland, will soon be operating a 1000 tons per day Landgard pyrolysis plant developed by Monsanto Enviro-Chem Systems, Inc. The City is planning to use the glassy fraction of the residue from this plant as an aggregate material for bituminous wearing surfaces.

Two samples of the *glassy aggregate* residue from the Monsanto pilot pyrolysis plant in Saint Louis, Missouri were analyzed by the University of Missouri at Rolla to determine the suitability of this residue for use in bituminous paving mixtures. The results of the particle size analysis of the pyrolysis residue are shown in Table 8.

Because of a deficiency in certain particle sizes, Marshall test specimens were molded with 16 percent stone and sand added to the washed pyrolysis residue mixtures. The results of the Marshall tests conducted at the University of Missouri at Rolla are summarized in Table 9. The properties of these specimens were compared to the Marshall design criteria for medium traffic as recommended by the Asphalt Institute and summarized below:

MARSHALL DESIGN CRITERIA FOR MEDIUM TRAFFIC

Property	Minimum	Maximum
Stability, Lbs.	500	---
Flow, .01 In.	8	18
Percent Air Voids	3	5

TABLE 6

SUMMARY OF BOEING COMPANY'S AGGREGATE TEST RESULTS

A. Loss on Ignition:

Grosse Pointe Aggregates:	2.9%
Chester Aggregates:	1.6%

B. Water Absorption:

Average for both residues	4.8%

C. Soft Fragments:

Crosse Pointe Aggregates:	0.6%
Chester Aggregates:	0.4%

D. Los Angeles Abrasion:

Grosse Pointe Aggregates:	39.6% Loss
Chester Aggregates:	43.0% Loss

E. Clay Lumps:

Grosse Pointe Aggregates:	1.3%
Chester Aggregates:	0.6%

TABLE 7
SUMMARY OF BITUMINOUS MIXES
USING INCINERATOR RESIDUE
PREPARED FOR THE BOEING COMPANY

Residue Source	Marshall Stability	Percent Asphalt	Voids Filled w/Asphalt	Flows	Voids Total Mix
Chester Plant Run	1150	9.0	72.7	15.3	6.9*
Laboratory Blended	1430	8.0	80.9	12.8	3.6
Grosse Pointe Plant Run	1440	9.0	65.7	13.3	10.1
Laboratory Blended	1930	7.5	71.3	14.5	6.4

* Fly Ash added 2.8% by weight

TABLE 8
SIEVE ANALYSIS OF MONSANTO PYROLYSIS RESIDUE

Sieve Size (Percent Passing)	Sample 1	Sample 2
1/2"	100	100
3/8"	92	97
No. 4	65	80
No. 8	34	51
No. 16	16	29
No. 30	5	16
No. 50	3	11
No. 100	2	7
No. 200	1	6

TABLE 9
RESULTS OF MARSHALL STABILITY TESTING
USING
MONSANTO PYROLYSIS RESIDUE

(Testing Accomplished by University of Missouri - Rolla)

Mixture: 84% Monsanto Residue
16% Stone and Sand

Asphalt Content Percent:	4.0	4.5	5.0	5.5	6.0	6.5
Stability, pounds	1870	1910	2030	2160	2050	1640
Flow, 1/100 inch	11	11	11.5	9.5	10.5	11
Unit Weight, pcF	131.5	123.9	134.7	138.5	139.1	138.5
Air Voids, %	11.68	10.11	8.17	4.96	3.92	3.69
Voids in Mineral Aggregate, %	13.55	13.04	12.37	10.33	10.37	11.32

MARSHALL DESIGN CRITERIA FOR MEDIUM TRAFFIC

Property	Minimum	Maximum
Percent Voids in Mineral Aggregate (1/2 inch maximum size)	15	---

None of the Marshall specimens that were tested fully met the Marshall design criteria with respect to air voids or voids in mineral aggregate. However, the resultant stability and flow values were well within the design criteria. The report from the University of Missouri noted that adjustments in asphalt content and aggregate particle size gradation should bring the values of the voids within specification limits. The conclusion of this investigation was that the washed pyrolysis residue should be considered for use in *glasphalt* type mixes, but that possible use of the unwashed pyrolysis residue in these mixes must be further determined.

As a follow-up to these tests, the Public Works Department of Baltimore County also evaluated bituminous mixtures using pyrolysis residue in place of washed sand. The purpose of this evaluation was to determine whether a base course mix using the glassy portion of pyrolysis residue could be designed which conforms to the Marshall design criteria of the Maryland State Roads Commission. (See Tables 10 and 11.)

7. *Personal Communication. Collins, Robert J. with Walter, C. Edward, President, Urban Aggregates, Inc., Baltimore, Maryland, May 23, 1975.*

A patent has been applied for by Mr. Edward Walter for asphalt pavement compositions utilizing municipal incinerator residue as the principal component. These compositions are intended for use primarily as road base material. The incinerator residue must have a maximum particle size of 2 inches and a maximum loss on ignition (LOI) of 15 percent. The ferrous metal content of the residue must not exceed 5 percent by weight and preferably be no more than 2 percent by weight. The compositions generally contain from 5 to 8 percent by weight of asphalt, 0 to 3 3/4 percent by weight of lime, and optionally mineral aggregate.

Laboratory testing was performed on treated incinerator residues from Baltimore, Maryland; Alexandria, Virginia; and Tonawanda, New York. A variety of asphalt mixtures were designed and molded in the laboratory. Most of these mixtures involved the

TABLE 10
BITUMINOUS CONCRETE MIX DESIGN
USING
PYROLYSIS PLANT RESIDUE
Bituminous Mixture Components

Sieve Size (Percent Passing)	Texas #10 Stone	Pyrolysis Residue	Texas #6 Stone	Bituminous Mix as Batched	Maryland State Roads Commission Specification
1 1/2"			100	100	100
3/4"		100	91	98	86 - 100
1/2"		97	48		
3/8"	100	94	32	83	66 - 90
#4	96	83	4	72	54 - 76
#8	89	67		62	40 - 64
#16	79	33		45	28 - 50
#30	64	9			
#50	41	2		17	10 - 27
#100	22	1			
#200	11			5	0 - 10

TABLE 11
RESULTS OF MARSHALL STABILITY TESTING
WITH
MONSANTO PYROLYSIS RESIDUE

(Testing Accomplished by Baltimore County Department of Public Works)

Mixture: 40% Monsanto Residue
40% Texas #10 Stone
20% Texas #6 Stone

Asphalt Content (Percent)	4.5	5.0	5.5	6.0	6.5
Stability	1050	1330	1430	1660	1710
Flow (.01")	10	9	9	10	11
Voids in Mineral Aggregates	22	20	22	20	20
Voids Total (%)	13	11	10	7	6
Voids Filled (%)	43	49	54	65	71

the combination of 50 percent incinerator residue with sand and crushed stone in varying proportions and the addition of approximately 2.5 percent commercial hydrated lime. It was generally found that Marshall stability, flow, and voids criteria were satisfied using mixes with 5.5 to 6.5 percent by weight of asphalt and from 40 to 55 percent by weight of treated incinerator residue.

A test section using ten tons of a base course composition containing incinerator residue was installed on July 12, 1972, at a bus stop location along Harford Road in Baltimore, Maryland. The incinerator residue in the mix comprised 50 percent by weight of the total mix and was taken from a batch-type incinerator in Baltimore and subjected to particle sizing to remove particles larger than 1 inch in diameter. The residue was combined with 20 percent sand, 10 percent No. 10 stone, 17.5 percent No. 4 stone, 2.5 percent lime, and 6.5 percent asphalt by weight.

The road base material was prepared in a conventional asphalt plant. The loss on ignition (LOI) of the residue was reduced from 3.8 percent to 0.7 percent in the aggregate dryer. The test strip in the field was installed with conventional paving equipment. After installation, two core samples were taken and analyzed. Test data indicate that Marshall design criteria for stability, flow, and air voids content are all satisfactory. The test section is reported to still be performing acceptably at this time.

5. SURVEY DATA ON UNITED STATES INCINERATOR PLANTS

The objectives of this study were to geographically locate presently operating U. S. incinerator plants and to determine the types and quantities of residues available from each of them for possible use in highway construction.

In the past ten years there have been four major surveys of U. S. incinerators.

1. The 1966 survey of Stephenson and Cafierro compiled comprehensive design and operational features on 290 incinerators then operating in the U. S. and Canada (2).

2. The 1970 Arthur D. Little (ADL) survey by Niessen compiled a listing of individual plants operating at that time with particular emphasis on air pollution control features (13).

3. Achinger and Baker in 1973 reviewed the number and general location of plants operating as of May 1972 (1). Composite data were given on 193 plants, rather than data on individual plants.

4. Richard Fenton, Assistant Administrator, New York City Environmental Protection Administration, began a questionnaire survey on the status of incinerator plants operating in August 1973. The final responses to the survey were received in December 1974. Emphasis in this survey was placed on detecting operational problems, particularly in regard to the handling of non-residential refuse. The appendix contains a sample questionnaire along with the summarized responses. These data were presented by Fenton at a meeting of the Solid Waste Processing Division of the American Society of Mechanical Engineers in New York City on January 29, 1975.

The survey conducted by Fenton provided the identities of presently operating plants along with data on their present output. Most of the other data from Fenton's questionnaires were not of direct pertinence to this study. A great deal of time and effort was spent by Fenton and his staff in obtaining the questionnaire responses. Many incinerator plants did not respond at first. Numerous surveys by different groups in recent years regarding air pollution, recycling and other environmental factors may have hindered the responses. Second appeals through the auspices of Regional Offices of the U. S. Environmental Protection Agency and State solid waste offices gradually elicited complete responses. However, not all questions in the questionnaire were answered by everyone. In some cases the responses only indicated that the plants were either operating or closed. Technical data from the three earlier surveys, particularly descriptive data on furnace and grate types were used in conjunction with Fenton's data to establish the types of incinerator residues produced.

5.1 A CLASSIFICATION SYSTEM FOR RESIDUE TYPES

A system for classifying incinerator residues according to composition and physical properties was needed to help in guiding their selection as highway construction materials.

Municipal refuse consists of a burnable and a non-burnable fraction. The burnable fraction represents 75 percent of the refuse weight. Therefore, compositional variation of incinerator residues would be expected to be highly dependent on the degree of burn-out of the burnable fraction. It had been found by Niessen and Chansky that municipal refuse composition in the United States varied only because of changes in the burnable fraction (14). Refuse composition varied according to three climatic zones, designated as seasonal, semi-seasonal and unseasonal. The non-combustible metal and glass fractions were present in a constant ratio in all three zones.

Large variations in refuse composition were found only in food wastes (higher in the seasonal northern zone) and yard wastes (much higher in the unseasonal southern zone). Variations in the combustible fractions would not change the non-combustible composition of incinerator residues.

Studies on individual components in municipal incinerator residues have confirmed the fact that with the exception of unburned combustibles, residue compositions tend to be reasonably uniform. The most thorough compositional analysis on residues from several different incinerators was made in a U. S. Bureau of Mines study by Kenahan et al. (11). In that study the residues of six different incinerators were compared. Five of the incinerators were in the Washington, D. C. area, the other was in Georgia. Most other compositional studies have examined residues from only one or two incinerators.

Kenahan's results are shown in Table 12 re-computed on a moisture and combustible free basis. The moisture contents ranged from 24.4 to 39.8 percent; the combustibles (paper, organics, and unburned carbon) ranged from 3.7 to 12.9 percent. The very low 3.7 percent combustible content was obtained in a rotary kiln. Two samples were taken at incinerator plant A. With the exception of incinerator plant F, which had rotary kilns, the residue analyses from the different incinerators on a combustible-free (and moisture-free) basis are in reasonable close agreement.

The physical character of the residue from the rotary kiln (F) was substantially changed by the vigorous tumbling action. This interferred with compositional analysis, since physical separation and visual inspection were used for analysis.

The two predominant factors which affect residue quality are seen to be: (1) degree of burn-out and (2) nature of the burning action. Both factors are inter-related and can be represented by the second factor. The nature of the burning action has a controlling influence over burn-out; well agitated incinerators produce a higher degree of burn-out than relatively unagitated incinerators. This factor permits the establishment of a classification system for incinerator residue types based solely upon the incinerator design.

TABLE 12
INCINERATOR RESIDUE ANALYSES
(Calculated from data of Kenahan et al. ref. 11)

COMPONENT	INCINERATOR						
	A-1	A-2	B	C	D	E	F*
Glass	55.2	45.1	52.4	43.3	50.2	47.6	
Ferrous Metals	23.6	32.8	27.0	34.4	28.1	36.6	(40.9)
Ash	15.9	18.6	16.9	18.7	19.4	13.1	(59.0)
Ceramics & Stone	1.2	2.3	2.8	2.9	1.5	1.4	(.1)
Non-ferrous metals	4.1	1.2	1.1	.8	.7	1.3	(.1)

*Glass and ash fraction were indistinguishable

Incinerator A - 3 furnaces, 1,050 ton/day continuous traveling grates

Incinerator B - 2 furnaces, 110 tons/day, Batch, dumping grates

Incinerator C - 5 furnaces, 425 tons/day, Batch, dumping grates

Incinerator D- 4 furnaces, 500 tons/day, Batch, rocking grates

Incinerator E - 5 furnaces, 750 tons/day, Batch, circular grates

Incinerator F - 2 furnaces, 500 tons/day continuous, rotary kilns

Six residue types are envisioned as representing the complete spectrum of municipal incinerator residues available nationally. They are:

Type 1 - Ultra-well-burned-out residue from rotary kilns are approximately 5 to 10 volume percent and 25 - 30 weight percent of the refuse input (2, 22). This represents virtually complete burn-out.

Type 2 - Well-burned-out residues from continuous incinerators having rocking grates, reciprocating grates, or roller grates. These residues are approximately 10 volume percent and 25 - 30 weight percent of the refuse input (2, 22). The major difference between Type 1 and Type 2 residues will be the ultra-high degree of burn-out and smaller screen size of particles of the well-tumbled product from rotary kilns.

Type 3 - Intermediately burned-out residues from the numerous continuous incinerators with traveling grates. These chain conveyor grates do not mechanically agitate or break down the burning refuse to any great extent. Their only virtue over batch burning is that they operate with a shallow bed of burning refuse. This permits better exposure to combustion air than a densely-packed batch-operated furnace. These residues can be expected to be approximately 20 volume percent and 30 - 35 weight percent of the refuse input (2, 22).

Type 4 - Poorly burned-out residues from batch incinerators or especially poorly operated continuous incinerators. Residues will be approximately 35 to 40 volume percent and 30 to 40 weight percent of the refuse input. Large wet items (i.e. rugs, phone books, pumpkins, etc.) would not be totally burned, since there would be no drying zone as in a well operated continuous incinerator. Variation in batch burning time would significantly affect the degree of burn-out.

Type 5 - Residues with especially low metal content. Tin cans and ferrous metals are sometimes removed from incinerator residues at a few plants in the South and West. Cans are the major metal component in incinerator residues (11). Their removal could significantly change bulk density and gradation which in turn should influence the highway construction characteristics of the residue.

Type 6 - Pyrolysis residues. Pyrolysis plants achieve volume reduction as incinerators do by oxidation and thermal decomposition of combustibles. However, slightly lower temperatures are generally used in pyrolyzers and excess air is excluded. The residues are approximately 30 to 40 volume percent and 30 to 40 weight percent of the refuse input (3). A strong similarity between Type 4 and Type 6 residues would appear to exist.

5.2 COMPILATION OF DATA ON PRESENTLY OPERATING INCINERATORS

The number of operating incinerator (or pyrolysis) plants has decreased from 193 to 142 since 1973, a decrease of approximately 25 percent. Many of these closings are the result of smaller, older plants being shut down. During this same time period, the total annual amount of refuse treated by incineration has declined from an estimated 21 million tons in 1973 to 16 million tons in 1975. This represents a decrease of 20 percent in the amount of refuse which is being incinerated. Consequently, the total amount of incinerator residue being produced over the same period is declining at a similar rate, from an estimated 7.4 million tons in 1973 to 5.5 million tons during this year.

Table 13 is a listing of the 142 incinerator and pyrolysis plants operating in the United States as of December 1974 based on a review of the data in Fenton's survey. The plants have been arranged and numbered (Column A) in alphabetical order by state. Column B identifies the plants by the numbers used in the Arthur D. Little (ADL) survey of Niessen (13). Precise identification and correlation of each plant with the ADL survey was made by examining the individual questionaires in Fenton's survey and noting appropriate identifying features tabulated in the ADL survey, such as plant location (Column C), year built (Column D) and plant capacity (Column E). In some cases sizeable expansions of plant capacity were noted to have occurred in the 5 - 6 years intervening between these surveys. Column F contains the reported number of hours per week that each plant is operated. Most continuous-grate incinerator plants were reported to operate on a 24 hour per day six day week (144

TABLE 13

LISTING OF CURRENTLY OPERATING INCINERATORS

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs/wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		CONNECTICUT (15)						
1.	217	Bridgeport	1958	300		(33,120)*	Batch/Mech.Stoked	4
2.	260	Bridgeport	1960	200		(22,090)	Batch/Rocking	4
3.	187	East Hartford	1956	350		(38,660)	Batch/Rocking	4
4.	37	Greenwich	1938	250	80	(11,500)	Cont./Rocking	2
5.	149	Hartford	1954	600	136	(62,486)	Batch/Mech.Stoked	4
6.	150	New Britain	1954	200	96	(14,720)	Batch	4
7.	188	New Canaan	1956	125		(13,800)	Batch/Mech. Stoked	4
8.	285	New Haven	1963	720		(69,550)	Cont./Trav.	3
9.	54	New London	1941	120		(13,250)	Batch/Rocking	4
10.	274	Norwalk	1962	360	132	(32,800)	Cont./Trav.	3
11.	56	Stamford	1942	350		(38,640)	Batch/Rocking	4
12.	New	Stamford		360		(34,780)	(Cont/Trav.)**	3
13.	354	Stratford	1968	264	144	(25,500)	Cont./Trav.	3
14.	129	Waterbury	1952	200		(22,080)	(Batch)	4
15.	189	West Hartford	1956	300	132	(31,240)	Batch/Mech.	4

* Column G brackets denote computed values
** Column H brackets denote estimated grate type

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		<u>FLORIDA (8)</u>						
16.	334	Ft. Lauderdale #1	1966	450	144	(37,260)	Cont./Recip.	2
17.	151	Ft. Lauderdale #2	1954	300		(33,120)	Batch/Mech.	4
18.	New	Lake Buena Vista	1971	100	140	(11,040)	(Batch)	4
19.	New	Miami (NE)		300		(28,980)	(Cont.)	3
20.	119	Miami (20th St)	1951	900	168	(101,430)	Cont/Mech Stoked	3
21.	298	Pompano Bch.	1964	300	120	(20,700)	Cont./Recip.	2
22.		Pompano Bch.		300		(28,980)	(Cont.)	3
23.	348	Tampa	1967	1,000	168	(96,600)	Cont./Rot.Kiln	1
		<u>HAWAII (3)</u>						
24.	261	Honolulu (Kapaloma)	1961	200	132	(36,904)	Batch/Recip.	4
25.	275	Honolulu (Kewalo)	1962	200		(22,080)	Batch/Recip.	4
26.	New	Honolulu (Waipahu)	1969	600	128	(48,300)	(Cont)	3

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		ILLINOIS (4)						
27.	236	Chicago (Calumet)	1959	1,200	168	(135,240)	Cont./Rocking	3
28.	New	Chicago (NW)	1970	1,600	168	(154,560)	Cont./Recip.	2
29.	287	Chicago (SW)	1963	1,200	168	(115,920)	Cont./Rot.Kiln	1
30.	223	Cicero	1958	500	168	(48,300)	Cont./Rot.Kiln	1
		INDIANA (1)						
31.	New	East Chicago		450		(43,470)	(Cont.)	3
		KENTUCKY (1)						
32.	209	Louisville	1957	1,000		(82,800)	Cont./Rot.Kiln	1
		LOUISIANA (6)						
33.	288	New Orleans (Algiers)	1963	200	144	(19,320)	Cont/Trav.	3

TABLE 13-Cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr. day	F Current Operation Hrs/wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		Louisiana-Cont'd						
34.	350	New Orleans (East)	1967	400	144	(33,120)	Cont/Recip.	2
35.	225	New Orleans (Fla. Ave.)	1958	400	144	(44,160)	Batch/Rocking	4
36.	361	New Orleans (7th St.)	1962	400		(38,640)	Cont/Trav.	3
37.	New	New Orleans (St.Louis St.)	1971	450		(37,260	Cont./Rocking	2
38.	29	Shreveport	1960	200	144	(16,560)	(Cont.)/Rocking	2
		<u>MARYLAND (4)</u>						
39.	26	Baltimore #3	1933	600	144	(49,680)	Cont./Rocking	2
40.	191	Baltimore #4	1956	800	144	(88,320)	Batch/Rocking	4
41.	323	Montgomery County	1965	1,200	168	(135,240)	Cont./Trav.	3
42.	100	Salisbury	1949	125		(13,800)	Batch/Mech.	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs/wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		MASSACHUSETTS (16)						
43.	238	Belmont	1959	150	45	(102)	Batch/Mech.	4
44.	239	Boston (South Bay)	1959	900	160	(115,920)	Batch/Rocking	4
45.	New	Braintree		240		(19,870)	(Cont.)	2
46.	130	Brookline	1952	180	128	(16,890)	(Batch/Mech.)	4
47.	364	Fall River		600	128	(42,228)	(Cont.)/Recip.	2
48.	New	Framingham	1973	500	168	(48,300)	(Cont/Recip.)	2
49.	79	Holyoke	1947	225	40	(6,900)	Batch/Manual	4
50.	305	Lowell	1964	400	120	(32,200)	Cont/Trav.	3
51.	226	Marblehead	1958	80	84	(4,906)	Batch/Rocking	4
52.	351	Newton	1967	500	144	(48,300)	Cont/Trav.	3
53.	277	Salem	1962	140		(15,460)	Batch/Mech.	4
54.	241	Waltham	1959	150	48	(5,520)	Batch/Rocking	4
55.	227	Watertown	1963	320	80	(19,620)	Batch/Mech.	4
56.	242	Wellesley	1959	150	80	(9,200)	Batch/Rocking	4
57.	324	Weymouth	1965	300	48	(11,040)	Batch/Mech.	4
58.	263	Winchester	1961	100		(11,040)	Batch/Rocking	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		MICHIGAN (5)						
59.	306	Central Wayne County	1964	800		(66,240)	(Cont.)/Recip.	2
60.	39	Detroit (St.Jean)	1938	200		(22,080)	Batch	4
61.	264	River Rouge	1961	50	80	(3,070)	Batch/Rocking	4
62.	138	S.E. Oakland Co.	1953	600		(66,240)	Batch/Mech.	4
63.	New	Clinton-Grosse Pointe	1972	600	120	(41,400)	Cont/Rotary Kiln	1
		MINNESOTA (1)						
64.	New	Kennsington Village	No data available yet					3-4
		MISSOURI (2)						
65.	192	St.Louis (North)	1956	400	116	(36,800)	Batch/Rocking	4
66.	121	St.Louis (South)	1951	400		(44,160)	Batch/Rocking	4
		NEW HAMPSHIRE (1)						
67.	36	Manchester	1937	100	168	(12,880)	Batch/Manual	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		NEW JERSEY (2)						
68.	325	Ewing	1965	240	40	(6,410)	Cont/Trav	3
69.	214	Jersey City	1957	600		(66,240)	Batch/Mech.	
		NEW YORK (31)						
70.	336	Babylon	1966	400		(33,120)	Cont/Rocking	2
71.	309	Beacon	1964	100		(11,040)	Batch/Rocking	4
72.	158	Buffalo	1954	600		(66,240)	Batch/Mech.	4
73.	310	Canajoharie	1964	50		(5,520)	Batch/Mech.	4
74.	278	East Chester	1962	200		(22,080)	Batch/Rocking	4
75.	311	Freeport	1964	150		(16,560)	Batch/Rocking	4
76.	292	Garden City	1963	175	60	(4,830)	Cont/Recip	2
77.	133	Hempstead	1952	750		(82,800)	Batch/Mech.	4
78.	338	Huntington	1966	150		(12,420)	Cont/Rocking	2
79.	279	Islip	1962	300		(28,980)	Cont/Trav.	3
80.	101	Lakawana		150	80	(9,190)	Batch/Manual	4
81.	103	Mt. Vernon	1949	600		(66,240)	Batch/Mech.	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		New York-Cont'd						
82.	326	Newburg	1965	240		(19,870)	Cont/Rocking	2
83.	48	New	1939	150		(16,500)	Batch/Manual	4
84.	243	NYC (Betts Ave.)	1959	1,000	144	(96,600)	Cont/Trav.	3
85.	143	NYC (Gansevoort)	1953	1,000	144	(96,600)	Cont/Trav.	3
86.	244	NYC (Greenpoint)	1959	1,000	144	(96,600)	Cont/Trav.	3
87.	265	NYC (Hamilton)	1961	1,000	144	(96,600)	Cont/Trav.	3
88.	159	NYC (South Shore)	1959	1,000	144	(96,600)	Cont/Trav.	3
89.	266	NYC (SW B'klyn)	1961	1,000	144	(96,600)	Cont/Trav.	3
90.	134	N. Hempstead (Denton Ave.)	1952	250	80	(15,330)	Batch/Mech.	4
91.	339	N. Hempstead (Roslyn)	1966	600	168	(57,960)	(Cont)/Rocking	2
92.		Old Bethpage		500		(48,300)		3,4
93.		Old Bethpage		500		(48,300)		3,4
94.	122	Port Chester	1951	120		(13,250)	Batch/Mech.	4
95.	245	Rye	1959	150	48	(4,970)	Batch/Mech.	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		New York-Cont'd						
96.	246	Scarsdale	1959	150		(16,500)	Batch/Mech.	4
97.	9	Tonawanda	1928	300		(33,120)	Batch/Mech.	4
98.	280	Valley Stream	1962	200		(19,320)	Cont/Trav.	3
99.	198	White Plains	1956	400		(44,160)	Batch/Rocking	4
100.	123	Yonkers	1951	400	120	(36,800)	Batch/Mech.	4
		<u>OHIO (12)</u>						
101.	New	Cedarville		15	24	(276)	(Batch)	4
102.	144	Cheviot	1953	20	44	(625)	Batch/Stationary	4
103.	312	Cincinnati (Center Hill)	1964	500	120	(40,250)	Cont/Trav.	3
104.	162	Cincinnati (West Fork)	1954	500	120	(46,000)	Batch/Mech.	4
105.	53	Dayton (N. Montgomery County)	1940	600		(57,960)		3,4
106.	199	Euclid	1956	200	80	(12,265)	Batch/Rocking	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr. day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		Ohio-Cont'd						
107.	124	Lakewood	1951	300	84	(18,390)	Batch/Manual	4
108.	355	Miami County	1968	150	144	(14,490)	Cont/Pusher	3
109.	201	Parma	1956	70	40	(2,145)	Batch/Rocking	4
110.	268	Sharonville	1961	500		(48,300)	Cont/Trav.	3
111.	281	Woodsville	1962	12	18	(220)	Batch/Mech.	4
112.	New	Dayton (S. Montgomery Co.)	1970	600		(57,960)	(Cont.)	3
		PENNSYLVANIA (13)						
113.	256	Bradford	1960	200	40	(6,110)	Batch/Rocking	4
114.	257	Delaware County #1	1960	800	168	(77,280)	Cont/Trav. + Rotary Kiln	1,3
115.	269	Delaware County #2	1961	500	120	(40,250)	Cont/Trav.	3
116.	282	Delaware County #3	1962	500	168	(56,350)	Cont/Trav.	3
117.	362	Lower Merion Township	1969	250	120	(17,250)	Cont/Rocking	2
118.	115	Philadelphia (Bartram)	1950	300	120	(27,600)	Batch/Mech.	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day.	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		Pennsylvania-Cont'd						
119.	341	Philadelphia (E. Central)	1966	750	120	(60,375)	Cont/Trav.	3
120.	1	Philadelphia (Harrogate)	1922	150	120	(13,800)	Batch/Stationary	4
121.	202	Philadelphia (NE)	1956	300	120	(27,600)	Batch/Mech.	4
122.	258	Philadelphia (NW)	1960	750	120	(60,375)	Cont/Trav.	3
123.	114	Philadelphia (SE)	1950	300	120	(27,600)	Batch/Mech.	4
124.	247	Whitemarsh Township	1959	100	40	(3,065)	Batch/Recip	4
125.	New	Harrisburg	1973	720	120	(49,680)	Cont/Recip	2
		RHODE ISLAND (2)						
126.	315	Pawtucket	1964	400	44	(10,880)	Cont/Trav.	3
127.	259	Woonsocket	1960	100	120	(9,200)	Batch/Mech.	4

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicated Residue Quality
		<u>TEXAS (2)</u>						
128.	329	Amarillo	1965	350	120	(32,200)	Batch/Recip.	4
129.	353	Houston (Holmes Rd.)	1967	800	138	(72,900)	Cont/Trav.	3
		<u>UTAH (1)</u>						
130.	342	Ogden	1966	450	144	(43,470)	Cont/Trav.	3
		<u>VIRGINIA (4)</u>						
131.	343	Alexandria #2	1966	300		(24,840)	Cont/Rocking	2
132.	74	Norfolk	1946	400	50	(14,720)	Batch (Mech.)	4
133.	357	Norfolk	1968	360	120	(24,840)	Cont/Recip	2
134.	295	Portsmouth	1963	350		(38,640)	Batch/Rocking	4
		<u>WASHINGTON, D. C. (1)</u>						
135.	New	Solid Waste Reduction Center #1		1,500		(144,900)	Cont/Rocking	2

TABLE 13-cont'd

A No.	B ADL No.	C Plant Location	D Year Built	E Refuse Capacity Tons/ 24 hr.day	F Current Operation Hrs./wk.	G Residue Output Tons/year	H Furnace Type & Grate	I Predicted Residue Quality
		<u>WISCONSIN (6)</u>						
136.	270	DePere	1961	300	45	(11,040)	Batch/Stationary	4
137.	345	Green Bay	1966	360	44	(13,250)	Batch/Stationary	4
138.	232	Neenah-Menesha	1958	300	168	(33,810)	Cont/Trav.	3
139.	358	Oshkosh	1968	350	80	(16,080)	Cont/Recip.	2
140.	331	Port Washington	1965	75	45	(2,760)	Batch/Recip.	4
141.	332	Sheboygan	1965	240	52	(6,955)	Cont/Rocking	2
		CURRENTLY OPERATING PYROLYSIS PLANTS						
		<u>MARYLAND (1)</u>						
142.	New	Baltimore	1974	1,000	168	(128,800)	Pyrolysis	6

hours/week). Many batch plants were reported to operate on a shorter cycle.

Column G is a tabulation of the estimated residue output from each plant. In a few cases figures on the residue output were reported in the survey questionnaires. However, in most cases calculated estimates for each plant had to be made.

The following procedure was used in calculating the residue output of each plant:

1. The type of residue was determined using the six-type classification system developed in Section 5.1. From this the estimated weight fraction of refuse remaining after incineration was obtained. The type of furnace and grate design of each incinerator is listed in Column H. Residue quality type designations are listed in Column I.

2. The operating schedule for each incinerator was determined using actual hours if reported in Column F or assuming six day, 24 hour/day operation if no data had been reported in the survey questionnaire. (This schedule was the most commonly reported one.) A 46 week operating period was assumed for all plants. This would allow six one-week shut downs for maintenance.

The residue output of each plant was calculated by multiplying the plant refuse capacity (Column E) by the number of operating days per year times the estimated weight fraction of refuse remaining after incineration. Residue outputs are tabulated in Column G.

5.3 ANALYSIS OF DATA

A tabulation of the quantities and types of incinerator residues available by state is given in Table 14. A total of 5,467,638 tons per year of all residues are potentially available. Residue types 3 and 4 represent the most abundant form of residues; 37.2 percent and 35.3 percent of the total respectively. Residue types 1 and 2 which have the highest degree of burn-out are respectively 7.7 percent and 17.4 percent of the total. The single pyrolysis plant in Baltimore producing

TABLE 14
QUANTITIES AND TYPES OF INCINERATOR RESIDUES
PRODUCED IN EACH STATE (TONS/YEAR)

Residue Type		1	2	3	4	6	Total Residue
1.	Connecticut		11,500	162,630	290,086		464,216
2.	Florida	96,600	57,960	159,390	44,160		358,110
3.	Hawaii			48,300	58,984		107,284
4.	Illinois	164,220	154,560	135,240			454.020
5.	Indiana			43,470			43,470
6.	Kentucky	82,800					82,800
7.	Louisiana		86,940	57,960	44,160		189,060
8.	Maryland		49,680	135,240	102,120	128,800	415,840
9.	Massachusetts		110,398	80,500	216,598		407,496
10.	Michigan	41,400	66,240		91,390		199,030
11.	Minnesota (not yet established)						
12.	Missouri				80,960		80,960
13.	New Hampshire				12,880		12,880
14.	New Jersey			6,410	66,240		72,650
15.	New York		128,200	627,900	557,020		1,313,120
16.	Ohio			161,000	137,881		298,881
17.	Pennsylvania	38,640	66,930	255,990	105,775		467,335
18.	Rhode Island			10,880	9,200		20,080
19.	Texas			72,900	32,200		105,100
20.	Utah			43,470			43,470
21.	Virginia		49,680		53,360		103,040
22.	Washington, D.C.		144,900				144,900
23.	Wisconsin		23,035	33,810	27,050		83,835
	Totals	423,660	950,023	2,035,090	1,930,064	128,064	5,467,638
	% of Total	7.7%	17.4%	37.2%	35.3%	2.4%	

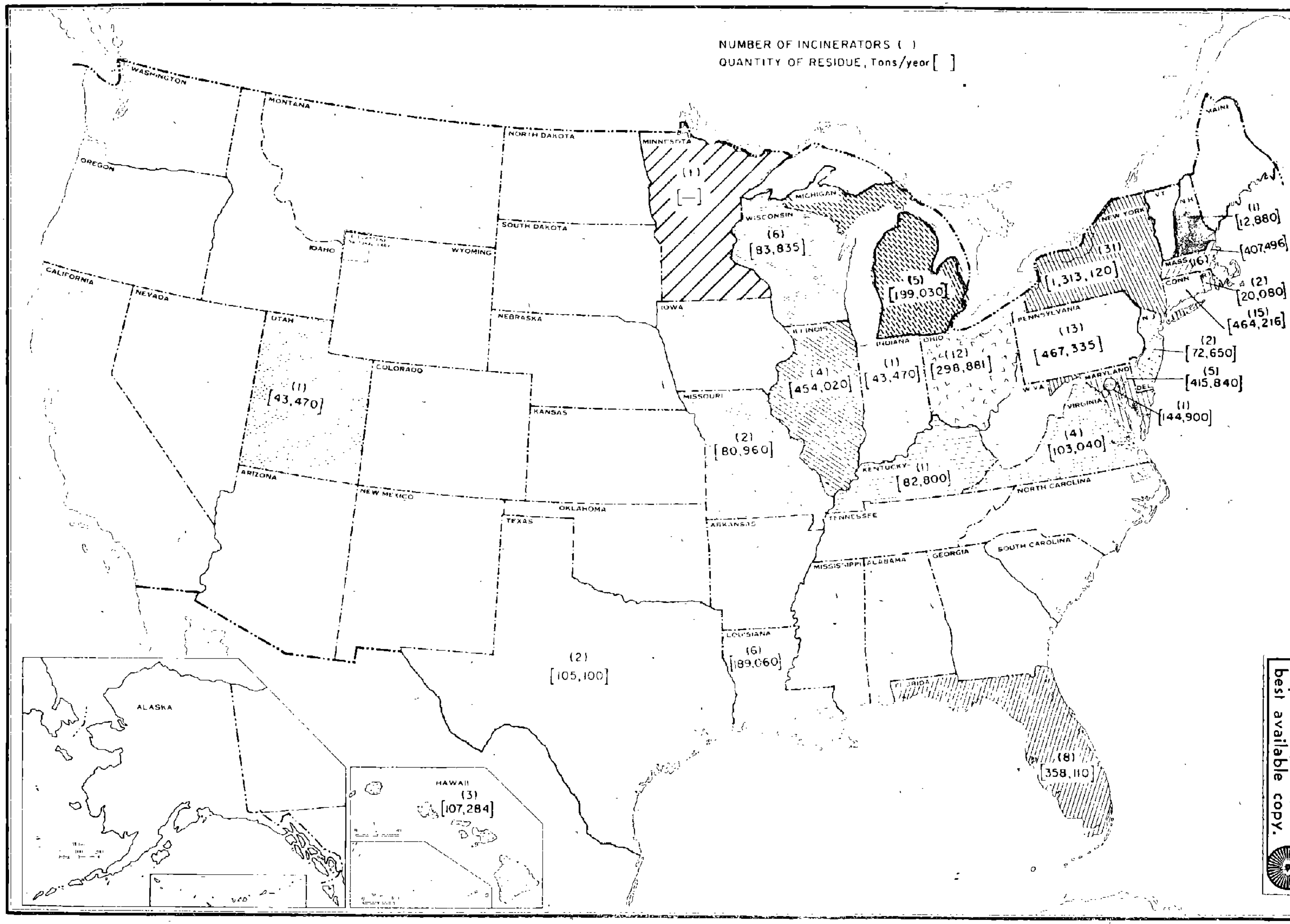

Figure 3. Map Showing Number of Incinerators and Residue Quantities Per State

Type 6 residue is 2.4 percent of the national residue total. Type 5 residue, which is material from which ferrous metals are salvaged is omitted from the table. Fenton's survey indicated that only three plants practiced metals recovery. The extent and continuity of these operations were not indicated. It is known that at the Harrisburg and the Philadelphia Northwest Incinerator only large ferrous scrap is salvaged. Cans which constitute the major ferrous component are not salvaged. For this reason a Type 5 designation was not included.

On the map in Figure 3, the geographical distribution of incinerators in the United States is shown. The number of incinerators and residue quantities for each state are shown on the map. The 22 states plus District of Columbia which have incinerators are cross-hatched, clearly showing that incineration is concentrated in the most populous states. California where extensive land-filling is practiced is the exception.

Table 15 is a tabulation ranking the number of incinerators per state. The states in the northeastern corner of the country have the most incinerators. Table 16 ranks residue quantities produced on a state basis. New York, Pennsylvania, Massachusetts, Connecticut and Florida are in the top six ranks for both number of incinerators and quantities of residues.

A break-down of residue distribution by major metropolitan areas in each state is given in Table 17. This table shows that the concentration of residues are near the largest cities in the country. It is near these large cities where the greatest utility of substitute highway construction materials exists. Quarries for sand, gravel, and aggregate materials have been depleted near many large cities.

Table 18 shows the 1970 aggregate requirements for highway construction purposes for each state next to each state's production of incinerator residue. The data on aggregate requirements are from Table A-3 of NCHRP Project Report 4-10/A, November 1973 "Waste Materials as Potential Replacements for Highway Aggregates" by R. H. Miller and

R. J. Collins. Eleven of the states could potentially supply over one percent of their aggregate needs from incinerator residues. The large cities in these states would utilize the major portion of these residues.

TABLE 15

RANKING OF STATES BY NUMBER OF INCINERATORS

	State	No. of Incinerators
1.	New York	31
2.	Massachusetts	16
3.	Connecticut	15
4.	Pennsylvania	13
5.	Ohio	12
6.	Florida	8
7.	Louisiana	6
8.	Wisconsin	6
9.	Michigan	5
10.	Illinois	4
11.	Maryland	4 (+ 1 Pyrolysis Plant)
12.	Virginia	4
13.	Hawaii	3
14.	Missouri	2
15.	New Jersey	2
16.	Rhode Island	2
17.	Texas	2
18.	Indiana	1
19.	Kentucky	1
20.	Minnesota	1
21.	New Hampshire	1
22.	Utah	1
23.	Washington, D. C.	1
		141 Incinerators + 1 Pyrolysis Plant

TABLE 16

RANKING OF STATES BY QUANTITIES OF RESIDUE

	State	Quantity of Residue (Tons/year)
1.	New York	1,313,130
2.	Pennsylvania	467,335
3.	Connecticut	464,216
4.	Illinois	454,020
5.	Massachusetts	407,496
6.	Florida	358,110
7.	Ohio	298,881
8.	Maryland	287,040 (415,840)*
9.	Michigan	199,030
10.	Louisiana	189,060
11.	Washington, D. C.	144,900
12.	Hawaii	107,284
13.	Texas	105,100
14.	Virginia	103,040
15.	Wisconsin	83,835
16.	Kentucky	82,800
17.	Missouri	80,960
18.	New Jersey	72,650
19.	Indiana	43,470
20.	Utah	43,470
21.	Rhode Island	20,080
22.	New Hampshire	12,880
23.	Minnesota	------
	Total:	5,338,838 (5,467,638)*

* Including 128,800 tons/year pyrolysis residue, Maryland ranks fourth

TABLE 17
RESIDUE QUANTITIES IN MAJOR METROPOLITAN REGIONS[1]

1. CONNECTICUT (464,216 Tons/year)[2]

	Tons/year	
Bridgeport - Stamford	186,930	
Hartford - New Britain	147,106	
New Haven	69,550	
New London	13,250	
Waterbury	22,080	
	438,916	(94.5%)[3]

2. FLORIDA (358,110 Tons/year)[2]

Miami - Pompano Beach	250,470	
Tampa	96,600	
	347,070	(96.9%)[3]

3. Hawaii (107,284 Tons/year)[2]

Honolulu	107,284	(100%)[3]

4. ILLINOIS-INDIANA (497,490 Tons/year)[2]

Chicago - East Chicago Indiana	497,490	(100%)[3]

5. KENTUCKY (82,800 Tons/year)[2]

Louisville	82,800	(100%)[3]

6. LOUISIANA (189,060 Tons/year)[2]

New Orleans	172,500	
Shreveport	16,560	
	189,060	(100%)[3]

TABLE 17-cont'd

	Tons/year
7. MARYLAND-WASHINGTON, D.C.	
Baltimore	138,000
(Baltimore Pyrolysis Residue)	(128,800)
Rockville-Washington, D. C.	280,140
Salisbury	13,800
	560,740 (100%)[3]
8. MASSACHUSETTS (407,496 Tons/year)[2]	
Boston	326,168
Lowell	32,200
	358,368 (87.9%)
9. MICHIGAN (190,030 Tons/year)[2]	
Detroit	199,030 (100%)[3]
10. MISSOURI (80,960 Tons/year)[2]	
St. Louis	80,960 (100%)[3]
11. NEW JERSEY (72,650 Tons/year)[2]	
Jersey City	66,240 (91.2%)[3]
12. NEW YORK (1,313,120 Tons/year)[2]	
Buffalo	108,550
New York City	579,600
Long Island	334,800
	1,022,950 (77.9)[3]
13. OHIO (298,881 Tons/year)[2]	
Cincinnati	135,175
Cleveland	32,800
Dayton	130,410
	298,385 (99.8%)[3]

TABLE 17-cont'd

14.	PENNSYLVANIA (467,335 Tons/year)[2]	Tons/year
	Delaware County	173,880
	Philadelphia	237,665
	Harrisburg	49,680
		461,225 (98.7)[3]
15.	RHODE ISLAND (20,080 Tons/year)[2]	
	Pawtucket-Woonsocket	20,080 (100%)[3]
16.	TEXAS (105,100 Tons/year)[2]	
	Amarillo	32,200
	Houston	72,900
		105,100 (100%)[3]
17.	UTAH (43,470 Tons/year)[2]	
	Ogden	43,470 (100%)[3]
18.	VIRGINIA (103,040 Tons/year)[2]	
	Alexandria	24,840
	Norfolk	78,200
		103,040 (100)[3]
19.	WISCONSIN (83,835 Tons/year)[2]	
	Green Bay	74,180 (88.5%)[3]

1 Metropolitan areas with at least 10,000 tons of residue/year are listed.

2 Residue in entire state.

3 Per-cent of state's total in major metropolitan areas

TABLE 18

COMPARISON OF 1970 HIGHWAY AGGREGATE REQUIREMENTS AND INCINERATOR RESIDUE PRODUCTION BY STATE

	STATE	Highway Aggregate Requirements (million tons/ year)	Incineration Residue Produced (million tons/ year)	Percent of Requirement
1.	Connecticut	5.15	0.464	9.0
2.	Florida	24.6	0.358	1.5
3.	Hawaii	---	0.107	---
4.	Illinois	37.9	0.454	1.2
5.	Indiana	23.6	0.043	0.2
6.	Kentucky	9.25	0.083	1.0
7.	Louisiana	19.8	0.189	1.0
8.	Maryland	12.48	0.416	3.3
9.	Massachusetts	12.0	0.407	3.4
10.	Michigan	31.5	0.199	0.6
11.	Minnesota	31.6	-----	---
12.	Missouri	17.1	0.080	0.5
13.	New Hampshire	3.64	0.013	0.4
14.	New Jersey	12.47	0.073	0.6
15.	New York	35.0	1.313	3.8
16.	Ohio	35.7	0.298	0.8
17.	Pennsylvania	38.6	0.467	1.2
18.	Rhode Island	1.64	0.020	1.2
19.	Texas	27.5	0.105	0.4
20.	Utah	6.1	0.043	0.7
21.	Virginia	19.2	0.103	0.5
22.	Wisconsin	29.5	0.083	0.3

6. CONCLUSIONS

1. Incinerator residues have been used in the past as fill material in highway construction in the United States, but not on a continuous basis. Very little technical data on these installations has been kept or reported. However, within the past five years several systematic laboratory and demonstration studies using residues have been initiated.

2. A number of thorough studies on the composition and physical properties of refuse and incinerator residues were conducted in recent years. These have shown that the non-combustible metal and glass fractions of the refuse and residues are relatively uniform nationally. The combustible (paper, organic, plastic and wood) fraction tends to vary in both refuse and incinerator residue. Therefore, the degree of burn-out is a principal indicator of residue composition.

   The physical character of incinerator residues, namely the particle size, the size distribution of components, and the degree of burn-out is totally dependent upon the type of agitation provided during burning. In continuous incinerator designs, rotary kilns provide vigorous agitation as do several designs of reciprocating and rocking grates. Traveling conveyor grates provide milder agitation. Batch furnaces even with good agitation suffer from poor burn-out because the large mass of solids restricts movement and burning. Accordingly, incinerator residue types can be classified by the type of furnace and grate design. Six residue types completely represent the spectrum of incinerator residues produced nationally.

3. There are presently 141 incinerator plants and one pyrolysis plant operating in 22 states plus the District of Columbia.

These produce approximately 5.5 million tons of residue per year. Most of the plants are located in the northeastern states. The majority of these plants (producing 37.2 percent of the residue total) have continuous traveling grates which produce a type 3 residue. Batch incinerators are still prevalent producing 35.3 percent of the residue total as a type 4 residue. Well-burned-out-residue types 1 and 2 comprise 25.1 percent of the residue total.

The incinerators being built within the past five years are of much bigger capacity than older ones. Everyone of these is known to have some form of heat recovery system.

4. The incinerator residues available in the United States could supply from 1 to 9 percent of the annual highway aggregate requirements of many of the states in which these incinerators are located.

7. REFERENCES

(All references used are listed in section 4.1 of this report)

Appendix

ASME RESEARCH COMMITTEE ON INDUSTRIAL AND MUNICIPAL WASTES
INCINERATOR SURVEY

APPENDIX

ASME RESEARCH COMMITTEE ON INDUSTRIAL AND MUNICIPAL WASTES

INCINERATOR SURVEY

1. ADDRESS OF INCINERATOR:

____

____

____

PHONE: (Include Area Code) ____________________

2. LOCAL TITLE OR DESIGNATION OF INCINERATOR:

____

3. INCINERATOR CAPACITY-TONS/DAY: ______________

4. YEAR OPENED (OR DATE ON CORNERSTONE): ______________

YEAR(s) OF MAJOR RENOVATION(s): ______________

5. a. DATE OF LAST PHYSICAL OR CHEMICAL ANALYSIS OF INCOMING REFUSE: ______________

b. DATE OF LAST FUEL ANALYSIS OF INCOMING REFUSE: ______________

6. HAS THERE EVER BEEN A RADIOLOGICAL CHECK OF INCOMING REFUSE?

( ) YES ( ) NO

IF YES, DATE: ______________

7. DATE OF LAST CHEMICAL ANALYSIS OF STACK GASES: ______________

8. DATE OF LAST CHEMICAL ANALYSIS OF QUENCHING WATER AND/OR OTHER LIQUID EFFLUENTS: ______________

9. DATE OF LAST CHEMICAL ANALYSIS OF RESIDUE: ______________

10. INTO WHAT DOES QUENCHING WATER AND/OR LIQUID EFFLUENT DISCHARGE?

____

11. IN WHAT KIND OF FACILITY ARE SOLID RESIDUES DISPOSED OF?

____

12. IS ALL INCOMING REFUSE WEIGHED? ( ) YES ( ) NO

13. NORMALLY, THE INCINERATOR IS OPERATED:

How many days per week? ______________

How many hours per day? ______________

How many hours per week? ______________

14. ARE SEPARATE TALLIES OF WEIGHT OF INCOMING REFUSE KEPT FOR RESIDENTIAL REFUSE AND NON-RESIDENTIAL REFUSE? ( )YES ( )NO

15. IF ANSWER TO ABOVE IS "YES":

A. For latest available year, what is tonnage and what is percentage of residential refuse _____tons _____% of total refuse

what is tonnage and what is percentage of non-residential refuse? _____tons _____% of total refuse

B. Above data is for the year: ______________

16. HAS THE NON-RESIDENTIAL REFUSE CREATED ANY PROBLEMS DURING RECENT YEARS?

a. Entering incinerator: ( ) YES ( ) NO

b. Weighing of load: ( ) YES ( ) NO

c. Maneuvering on dumping floor: ( ) YES ( ) NO

d. Dumping into storage pit: ( ) YES ( ) NO

e. Mixing refuse in pit: ( ) YES ( ) NO

f. Charging furnaces: ( ) YES ( ) NO

g. In furnaces: ( ) YES ( ) NO

h. In stack discharge: ( ) YES ( ) NO

i. In liquid effluent: ( ) YES ( ) NO

j. In residue: ( ) YES ( ) NO

k. Elsewhere in incinerator: ( ) YES ( ) NO

17. IF ANY ANSWERS TO ABOVE ARE "YES", PLEASE DESCRIBE PROBLEM:

DATA FURNISHED BY: ______________________________
(Please Print Name)

____
(Title)

____
(Address)

____

____

____
(Date)

____
(Phone - Please Include Area Code)

PLEASE RETURN TO:

Asst. Administrator Richard Fenton
Chairman, Sub-Committee on
State of the Art, Municipal
American Society of Mechanical Engineers
Environmental Protection Administration
Room 2356 Municipal Building
New York, New York 10007

A.S.M.E. INCINERATOR SURVEY

Dec. 1974
135 Responses

Question 5

a) Date of last physical or chemical analysis of incoming refuse?

Yes	52
No	38
No Response	45
	135

b) Date of last fuel analysis of incoming refuse?

Yes	38
No	45
No Response	52
	135

Question 6

Has there ever been a radiological check of incoming refuse?

Yes	1
No	114
No Response	20
	135

Question 7

Date of last chemical analysis of stack gases?

Yes	72
No	28
No Response	35
	135

Question 8

Date of last chemical anlaysis of quenching water and/or other liquid effluents?

Yes	49
No	38
No Response	48
	135

Question 9

Date of last chemical analysis of residue?

Yes	41
No	44
No Response	50
	135

Question 10

Into what does quenching water and/or other liquid effluent discharge?

Sewer, catch basin, municipal drainage system	58
Settling or holding lagoon, settling basin, settling pond, settling trench, sedimentation trench	24
Clarifier	9
Recirculated	6
Drainage ditch, drain field, natural drain	5
Navigable waters, ocean	4
Sewage treatment plant	4
Leaching field	2
Dry well, ground seepage	1
No Response	22
	135

Question 11

In what kind of facility are solid residues disposed of?

Landfill, quarry landfill	125
Dump, city refuse area, abandoned quarry	9
Metal recycled	(3)
No Response	1
	135

Question 12

Is all incoming refuse weighed?

Yes	95
No	18
No Response	22
	135

Question 13

What are hours of incinerator operation?

a) Hours per day, weekday:

24 hours / day	75
16 "	15
8 "	23
No Response	22
	135

b) Weekend hours:

Closed	50
Open Sat:	
8 hours or less	19
16 hours	4
24 hours	20
As needed	4
Open 24 hours Sat. and Sun.	16
No Response	22
	135

Question 14

Are separate tallies of weight of incoming refuse kept for residential refuse and non-residential refuse?

Yes	55
No	59
No Response	21
	135

Question 15

If answer to above is "Yes", what is percentage of non-residential refuse?

0 - 20%	21
21 - 40%	12
41 - 60%	12
61 - 80%	1
81 -100%	0
No Response	9
	55

Questions 16 and 17

Has the non-residential refuse created any problems during recent years?

a) Entering incinerator:

Yes	8
No	97
No Response	30
	135

Some trucks too big to enter - must be hand unloaded	1
Can't enter permises after operating hours due to easement across property	1

b) Weighing of load:

Yes	6
No	99
No Response	30
	135

Scales not long enough for oversize trucks	3
No scale	2

c) Maneuvering on dumping floor:

Yes	9
No	95
No Response	31
	135

Oversize trucks have difficulty maneuvering on dumping floor	5
Dumping floor too small	1
Ceiling too low for trucks	1

d) Dumping into storage pit?

	Yes	9
	No	93
	No Response	33
		135

Hand unloading of some trucks takes too long	2
Spillage onto dumping floor due to ill-designed dumping mechanism and detachable containers	2
No provisions for removing bulky items, chemicals	3
Canopy height too low for compactors and roll-offs	2
Storage pit too small for peak periods	2

e) Mixing refuse in pit:

	Yes	21
	No	82
	No Response	32
		135

Long or bulky items, mainly industrial wastes and liquids, cause problems	12
Large objects pass unnoticed	2
Pits too small for effective mixing	2
Very difficult to mix with clam buckets	1
Non-burnables get under stoker and cause problems with drive chains and grates	1

f) Charging furnaces:

	Yes	33
	No	72
	No Response	30
		135
Large items get caught in feed hopper or chute (3 mention 4' limit)	30	
Fire occasionally spreads from loading hoppers to storage pit, due to long paper streamers	1	
Excessive flashing	1	

g) In furnaces:

	Yes	43
	No	63
	No Response	29
		135
Highly inflammable material, such as grease, plastics, rubber, parafin, magnesium, causes local hot spots, damaging grates or refractory	29	
Heavy metal items jam and damage rubber arms, ash scrapers, grates	13	
Excessive slagging on grates due to melting of non-ferrous metals - also clinkers block slots in grates	6	
Large objects cannot be discharged through dropping grates to conveyor	3	
Excessive slagging of refractory due to physical and chemical characteristics of non-combustible part of refuse	2	
Metal bonds itself to wall of furnace causing blockage	1	

h) In stack discharge:

Yes	27
No	69
No Response	39
	135

Industrial material such as parafin, rubber tires, film, carbon paper, cardboard, tobacco, cause excess stack emissions	21
Liquid waste, PVC's, cause excess SO_2 and HCl	1
Fly ash in stack discharge	2
Wet baffle only	1

i) In liquid effluent:

Yes	12
No	84
No Response	39
	135

Effluent high in pH, causing damage to exposed metal	3
Dyes and chemicals in ash water	4
Heavy metals in water	1

j) In residue:

	Yes	17
	No	84
	No Response	34
		135
Large objects such as tramp metal in residue cause special handling problems (jam conveyors, etc.)	15	
Residue wedges between drag chain and traction wheel causing shear pin to break	1	
Poor reduction	1	

k) Elsewhere in incinerator:

	Yes	17
	No	83
	No Response	35
		135
Dust in air is dangerous due to health hazard and possibility of explosion	2	
Floatables cause blockage of re-cycled water for air pollution spray nozzles	1	
Problems with clarifiers	1	
Constant maintenance of traveling grates	1	
Plastic buildup on walls of unit	1	
Fly ash from film negatives in combustion chamber	1	
Conveyor problems	2	