AIR POLLUTION ASPECTS OF THE IRON FOUNDRY INDUSTRY

FEBRUARY, 1971

for

Division of Air Quality and Emissions Data
Air Pollution Control Office
Environmental Protection Agency

Contract No. CPA 22-69-106

Prepared by
A. T. Kearney & Company, Inc.
Chicago, Illinois

BIBLIOGRAPHIC DATA SHEET

1. Report No.	APTD-0806
2.	
3. Recipient's Accession No.	
4. Title and Subtitle	AIR POLLUTION ASPECTS OF THE IRON FOUNDRY INDUSTRY
5. Report Date	February 1971
6.	
7. Author(s)	
8. Performing Organization Rept. No.	
9. Performing Organization Name and Address	A. T. Kearney & Company, Inc. Chicago, Illinois
10. Project/Task/Work Unit No.	
11. Contract/Grant No.	CPA 22-69-106
12. Sponsoring Organization Name and Address	Division of Air Quality and Emissions Data Environmental Protection Agency Office of Air Programs Research Triangle Park, N. C. 27711
13. Type of Report & Period Covered	
14.	

15. Supplementary Notes DISCLAIMER:This report was furnished to the Office of Air Programs by A. T. Kearney & Company, Inc., Chicago, Illinois in fulfillment of Contract CPA-22-69-106

16. Abstracts

A systems analysis study of the iron foundry industry is presented with particular emphasis on the melting area. The study presents detailed information on the following topics: Trends of the iron foundry industry; The iron foundry process, (which includes; iron production, raw material storage, furnace charge preparation, iron melting, molding, pouring, shakeout, cleaning, heat treating, finishing, sand conditioning, coremaking, and pattern making); Emissions generated and their control; Recommended for testing particulate emissions from iron foundry cupolas.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Foundries
Foundry practice
Melting
Molding techniques
Foundry core making
Foundry core sands
Foundry ingots
Emission
Air pollution control equipment
Furnace cupolas
Electric arc furnaces
Induction furnaces
Reverbatory furnaces

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	UNCLASSIFIED	~~257~~ 260
	20. Security Class (This Page)	22. Price
	UNCLASSIFIED	

AIR POLLUTION CONTROL OFFICE

AIR POLLUTION ASPECTS OF THE IRON FOUNDRY INDUSTRY - FEBRUARY, 1971

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

LIST OF EXHIBITS

LIST OF EXHIBITS
(continued)

LIST OF EXHIBITS
(continued)

ACKNOWLEDGEMENTS

A. T. Kearney & Company, Inc. gratefully acknowledges the many people and organizations who cooperated and assisted in this study.

We acknowledge the cooperation and assistance provided by the American Foundrymen's Society and the Gray and Ductile Iron Founders' Society in furnishing information.

We acknowledge the staff of APCO for their assistance and guidance.

This report was prepared by a project team of A. T. Kearney staff. The overall direction was under Mr. E. Stuart Files, Vice President of A. T. Kearney & Company, Inc. The Project Director was Mr. Joseph H. Greenberg, Principal, and the other members of the team were Mr. Robert E. Conover, Senior Associate and Mr. Bernard Gutow, Associate.

AIR POLLUTION CONTROL OFFICE

AIR POLLUTION ASPECTS OF THE IRON FOUNDRY INDUSTRY FEBRUARY, 1971

I - SUMMARY

INTRODUCTION

The Air Pollution Control Office has the task of developing technology for a national program for control of air pollution and, as a part of this program, is conducting a series of systems analysis studies of various industries which are primary sources of air pollution. These studies are being conducted by the Division of Process Control Engineering. This study is directed at the iron foundry industry, with particular emphasis on the melting area.

For the purposes of this study, the iron foundry industry is defined as those shops that melt iron (including iron and steel scrap) in furnaces, pour the molten iron into molds, and alloy and/or treat the iron in either the molten or cast state with processes limited to making gray, malleable and nodular or ductile cast iron. This definition excludes blast furnace processes, processes for converting iron to steel, and processes wherein molten iron is not cast in molds, such as metal abrasive shot.

THE EMISSIONS PROBLEM

The last 20-25 years have seen significant advances in the technology of making iron castings. The use of cupolas as the main melting source is decreasing and being replaced with the advanced technology of melting with electric arc and induction furnaces. In addition to increasing the production capacities of the foundries, the electric furnaces have made it possible for the foundries to use charge materials such as iron borings and steel turnings, sheet steel, etc., which were previously considered impractical for use as cupola charge without extensive preparation. The availability and lower cost of such materials, better control of the metallurgical process involved in making molten iron, and freedom from the use of coke as a fuel have made electric furnaces very popular with some foundries. In spite of all these advancements, the cupola has remained the main melting unit in the iron foundry industry and continuing efforts are being made to improve its performance and that of the charge material. Improvements in foundry melting technology have not resulted in full elimination of the pollutants emitting from the foundries into the atmosphere.

The pollutants discharged by the iron foundry industry are:

1. Emissions from melting furnace operations, such as smoke, metallic oxides, oil vapors and carbon monoxide.

2. Emissions from other dust-producing operations within the plant, such as sand fines, metal dust and coke dust.

3. Odors and gaseous compounds such as fluoride fumes, vapors and facing fumes from both sources. The physical difficulties of satisfactory collection of pollutants are not easily solved and, in most cases, costs of satisfactory collection are

quite high. Gases from foundry furnaces are hot and must be cooled before collection. If recirculated water is used for cooling and dust collection, corrosion problems may be introduced. Cost of fresh water is often prohibitive requiring recirculation in most cases. Most metallic oxides from melting operations are extremely small in size, to about 0.7 microns, and require very efficient equipment for collection.

Particulate emissions have been a point of focus for concentrated efforts in the control of air pollution. However, gaseous emissions and odors from the foundries have not been given much attention, and the foundry industry now has to take steps to suppress these discharges into the atmosphere. Many of the odors in the foundries result from coremaking and shell molding operations, but the common gaseous emissions also include vapors from melting oily metal scrap, painting operations, inoculation of metal, and from metal pouring into molds.

CONCLUSIONS

The lack of correlation between standard furnace design factors and emissions levels requires that the explanation for the wide variance in type and quantity of emissions lie with cupola operating factors. This is borne out of the fact that all variables proven to affect emissions levels, or indicating a probability of affecting emissions levels, relate more to the operation of the cupola than to its design. These operating factors can be easily divided into two quite distinct groupings with some cross effects from one group to the other.

The first group consists of variables related directly to cupola operation, including specific blast rate, blast temperature, type of lining, and operating variables of the afterburner. The afterburner itself is an emission control device but adjustment of gas and combustion air is considered here as a variable for the melting system. These variables are relatively inflexible and are determined by required, or desired, operating characteristics.

The second group of variables concerns the quantity and quality of charge materials. These include metal to coke ratio, use of oxygen or natural gas, and the use of briquettes which often contain oil or cementitious materials. Also, contaminants or alloying materials may occur in the metallic charge. These factors are highly variable, often changing from charge to charge. This second group is more controllable, but at some cost.

Insufficient data prohibit the quantitative evaluation of the total effect of all variables in the first group compared to all variables in the second group. The data suggest, however, that the type and quantity of cupola emissions are affected more by the quantity and quality of charge materials. Certainly little or no limestone dust, coke particles, or oil vapor and other combustibles will appear as emissions unless these materials are charged into the cupola. Similar statements can be made for zinc, lead, aluminum, chromium, cadmium, copper, silicon and other oxides, particularly when their formation is abetted by the injection of oxygen, or high blast rates.

Certain relationships expected to be identified were not discovered. Blast air temperature, with a demonstrable effect on coke rate, must by extension show a secondary effect on the emissions level. The use of afterburners in the cupola stack has been shown to aid in the incineration of combustibles. Incorporation of these devices would no doubt noticeably lower the emission levels. The fact that these relationships are not identified might be attributed to two factors possibly affecting all the analyses: the quantity and quality of the test data.

Stack testing is not an exact science at this time and no single technique has been accepted by the industry. Methods and equipment used to obtain the data are discussed later. Reproducibility of results is difficult with any given technique by a single testing firm, even for a stable emissions producing system. With relatively unstable conditions as exist in cupola furnaces and the generally poor working conditions existing at the top of cupola stacks, variation in results would be expected. When this situation is further compounded by the use of different techniques, equipment, and testing companies to obtain data for comparison and analysis, the confidence level of the data must suffer, despite the high degree of professionalism of the laboratories performing the tests. As a result of this condition, all data used in this analysis have undergone critical evaluation before acceptance.

II - TRENDS OF THE IRON FOUNDRY INDUSTRY

The iron foundry industry in the United States is in the peculiar position of having its output increase in recent years both on a tonnage and a dollar basis, while at the same time there has been a decrease in the number of active installations. These foundries are located in 48 states, although 80% are located in only 13 states. In fact, 1,116 or 62% are located in 25 major metropolitan areas of United States cities. Of all iron foundries, only about 525, or 29%, can be classified as medium and large foundries, employing more than 100 people, and only 91 can be called very large, employing over 500 people. Thus, by far the majority of foundries are small installations, many being located in small communities.

GEOGRAPHIC LOCATIONS OF IRON FOUNDRIES

The distribution of iron foundries by states and by major metropolitan areas is shown in Exhibit II-1. The highest concentration is in the states which border on the Great Lakes, namely, Pennsylvania, Ohio, Michigan, Illinois, Wisconsin, New York and Indiana. This group of seven states contains almost half of all of the iron foundries in the United States and more than half of the iron castings capacity. The State of California contains the greatest concentration of iron foundries in the western half of the country, with one-third of the iron foundries in that 17-state area being in California. Other areas of high iron foundry concentration are in the southeastern states and in the northern states bordering on the west bank of the Mississippi River.

The variations which have occurred in the distribution of iron foundries by states during the period of 1963-1969 are given in Exhibit II-2.

IRON FOUNDRY POPULATION

The population trends in the foundry industry have been developed in Exhibit II-3.

The total number of foundries of all types has remained relatively constant during the postwar period, ranging from 5,000 to 5,800 and averaging approximately 5,400. However, the iron foundry population has shown a steady decline, from 3,200 in 1947 to 1,670 in 1969. If this decline is continued, the number of foundries is projected to be approximately 1,000 by 1980. However, the average size of iron foundries has been increasing steadily, with average annual production per foundry going from 3,800 tons in 1947 to 5,300 tons in 1959 and to 8,700 tons in 1969. By 1980, the average production per iron foundry is projected to be approximately 16,500 tons per year.

An analysis of the population of iron foundries with respect to size of foundry has shown that almost the entire decline in foundry population has been among the small foundries, with employment of under 100 per foundry. The number of medium sized foundries has remained almost constant, while the number of large foundries has increased slightly. The number of small foundries has declined by one-third from 1959 to 1969 and is expected to further decline to only about half of the 1969 population by 1980.

IRON FOUNDRY PRODUCTION

Annual castings production in the United States has varied widely, depending on the economy, with the ranges during the postwar period as follows:

Iron Foundry Production [1, 2]

	Production Tons per Year		
Type of Metal	Minimum	Maximum	Last 5-Year Average
All Metals	13,200,000	20,800,000	20,000,000
All Reported Cast Iron	11,032,000	17,084,000	16,329,000
Cast Iron from Iron Foundries	10,000,000	14,486,000	13,817,000
Gray Iron	9,340,000	11,936,000	11,650,000
Malleable Iron	661,000	1,227,000	1,075,000
Nodular Iron	-	1,570,000	1,092,000

The complete castings production picture has been shown graphically in Exhibit II-4. The data, as reported by the Department of Commerce, included the production of ingot molds. However, only about 30% of ingot molds are produced from gray iron melted in cupolas, with the rest being produced from direct blast furnace metal. Since castings production from direct metal was excluded from this study by definition, and additionally has already been covered by the iron and steel industry study, the estimated portion of ingot mold production from this source was deducted from total iron castings production.

IRON FOUNDRY MELTING EQUIPMENT

The cupola is still the most common method of melting iron with about 1,930 cupolas in 1969 for a combined capacity of 18,570 TPH. This is a decline of about 900 cupolas in the past ten years. This decline can be expected to continue, although at a decreasing rate, as more foundries are abandoned, and others convert from cupola to electric melting. The trend toward decline in the number of cupolas is expected to continue for the foreseeable future, with the projected number being reduced to approximately 1,000 by 1980. The use of the cupola from the postwar period is depicted in Exhibit II-5.

The trend toward electric melting in iron foundries has been accelerating rapidly, as shown in Exhibit II-6. Although some scattered electric melting installations existed in iron foundries prior to the mid-1950's, the great majority of the installations were made during the period of 1960-1970. The most recent census of foundries, taken in 1969, has revealed that there were some 374 electric arc furnaces installed in 176 iron foundries in the United States.

Since many foundries which produce both iron and steel castings use the same melting furnace for both purposes, the actual number of arc furnaces used for iron melting has been estimated to be approximately 200, located in some 100 foundries.

The number of arc furnace installations for iron melting has been increasing at a rate of about 15 furnaces per year. If this rate were to continue, the number of such furnaces could be expected to reach approximately 350 by 1980.

For the most part, the electric arc furnace installations have been for the replacement of cupolas in existing foundries, although there have been several new foundries built in recent years in which arc furnaces were installed. The number of arc furnaces melting iron will, therefore, be higher than the straight line projection, possibly in the range of 400 to 450 furnaces by 1980.

In 1969, there also were 495 coreless induction furnaces installed in 191 iron foundries. Approximately half of these furnaces were in foundries which also produced steel castings. Since many of these iron and steel foundries use the same furnaces for melting both metals, the actual number of these coreless induction furnaces which are used for melting iron is estimated to be approximately 300, located in some 125 foundries. The number of coreless induction furnace installations has been increasing at a rate of approximately 50 per year. This trend will probably accelerate, resulting in an estimated 700-800 furnaces in iron foundries by 1980.

OTHER EQUIPMENT IN IRON FOUNDRIES

All foundries employ some kind of molding practice with almost all iron foundries using sand molding. The trend is toward modern mechanized or semiautomated molding, some of which employ conveyors for moving molds past each of the molding stations. This can be expected to increase as more foundries automate or mechanize their operations.

Coremaking is another area that is undergoing rapid changes, with the trend being away from oil-bonded, baked sand cores, toward chemically bonded, thermally cured or airset cores.

CONCLUSIONS

These figures and trends are of importance at this time, in that they tend to emphasize certain factors having a direct bearing on this study. These factors can be summarized as follows:

1. The number of iron foundries is still declining, but at a lesser rate. However, there were about 1,670 installations in 1969.

2. The number of cupola installations is still declining, but also at a lesser rate. The majority of iron foundries, however, still use cupolas for melting and will no doubt continue to do so for many years.

3. Only 5% of the total number of iron foundries can be classified as large foundries. However, 62% of all iron foundries, including most of the larger ones, are located in 25 large metropolitan areas.

III - THE IRON FOUNDRY PROCESS

The iron foundry consists of a number of distinct but strongly interconnected operations. In a large production foundry, each of the operations can be highly mechanized, or even automated, while the smaller foundries still may retain many manual techniques.

All foundries utilize certain basic operations consisting of:

1. Raw material storage and handling.
2. Melting.
3. Pouring into molds.

Other processes present in most, but not all, foundries include:

1. Molding.
2. Sand preparation and handling.
3. Mold cooling and shakeout.
4. Casting cleaning, heat treating, and finishing.
5. Coremaking.
6. Pattern making.

A simplified, schematic flow diagram encompassing most of these processes is presented in Exhibit III-1.

Each operation contains equipment and processes capable of producing emissions which may include gas, fume, smoke and particulate matter. The latter can range from metal dust from grinding operations, that is relatively easy and inexpensive to collect, to extremely fine ferrous and nonferrous oxides from melting furnaces, that are very expensive to collect. The sources of these emissions are schematically indicated in Exhibit III-1, and the operations are described in the following paragraphs.

GRAY IRON PRODUCTION

Exhibit III-2, Process Flow Diagram for Gray Ductile and Malleable Iron, outlines the most common flow pattern in the iron foundry industry. The flow begins with the raw material storage area including the scrapyard and stores facilities for scrap, pig iron, alloys, sand, binders, and other raw materials. The furnace charge is made up in, or adjacent to, the scrapyard and consists of the metallics, flux materials, and, in the case of cupola melting, coke for fuel.

Melting furnaces for iron include the following principal types:

1. Cupolas
2. Electric Arc
3. Electric Induction
4. Reverberatory.

The charge material is transferred to the melting furnace, and the resultant molten iron is tapped into a temporary holding unit or into a ladle for pouring into completed molds.

The holding unit may be a large ladle or forehearth to accommodate the constant flow of metal from a continuous-tap cupola or it may be a gas fired or electric powered furnace also used to increase the temperature of the iron. Holding furnaces are also utilized with electric melters for accumulation of hot metal, superheating, and analysis adjustment.

Molten metal from the forehearth or holding furnace is transferred to a pouring ladle, from which molds are filled, or to a large "bull" ladle used for filling a number of smaller pouring ladles. In some production foundries, metal is transferred from the furnace by ladle to a channel induction holding furnace adjacent to the pouring zone of a molding line where the molds are filled from smaller pouring ladles or from an automated pouring machine. The holding furnace is capable of restoring heat lost during the transfer and providing superheating where desired. Chemical additions to the molten iron while in the ladle normally include desulphurizing agents, usually some form of sodium carbonate.

The molding area is supplied with molding sand mixed with the required additives to permit the production of satisfactory molds of green sand, dry sand, dry baked sand, shell or hot box sand, or other molding material. After the mold has been completed and closed, it is filled with hot metal, cooled sufficiently to insure solidification, and moved to the shakeout area where the sand and casting are separated by manual or mechanical means.

In green sand molding, the used sand from the shakeout, plus spill and overflow sand, is returned to the sand preparation system for reconditioning and reuse. Used sand from other molding processes is either disposed of or transferred to a thermal wet or dry sand reclamation system.

After being separated from the molding sand in the shakeout, the castings commonly are cooled, sorted, trimmed, and then cleaned by shotblasting. Processing after cleaning includes chipping and grinding. Heat treatment may be specified for certain types of castings before machining. Surface coating applications such as paint or ceramic coatings are normally the final operation.

DUCTILE IRON PRODUCTION

The manufacture of ductile iron castings is essentially the same as the production of gray iron except for magnesium treatment and minor analysis modifications, and for the more extensive heat treatment which is sometimes required. The inoculants that produce the desired graphitic nodularization are commonly added to the molten metal in the ladle at a special station. The resultant smoke and fume emissions, as well as the momentary pyrotechnics, generally require a ventilated and partially shielded station to protect foundry personnel.

MALLEABLE IRON PRODUCTION

Malleable iron process flow is also similar to gray iron flow with the exception of an annealing operation required to convert the as cast "white" iron into malleable iron, and the press straightening sometimes required to correct the warping that results from the annealing process. In other regards the process flow for malleable iron is the same.

Specifications for various classes of gray, ductile, and malleable iron are tabulated in Exhibits III-3, III-4 and III-5.

RAW MATERIAL STORAGE & FURNACE CHARGE PREPARATION

Raw Material Receiving and Storage

The raw materials used for iron production fall into the following classifications:

1. Metallics
   - (a) Pig Iron
   - (b) Iron and steel scrap
   - (c) Turnings and borings (loose or briquettes)
   - (d) Ferroalloys
   - (e) Foundry returns
2. Fluxes
   - (a) Carbonate type (limestone, dolomite, soda ash)
   - (b) Fluoride type (fluorspar)
   - (c) Carbide type (calcium carbide)
3. Fuels-Coke (for cupolas)
4. Refractories

These materials, except for foundry returns, are received by railcar or truck, usually unloaded by crane and stored in the foundry scrapyard. Exhibit III-6 Process Flow Diagram for

Raw Material Storage and Furnace Charge Makeup, outlines the common flow patterns in the iron foundry industry.

Although open stockyards are still common, the use of covered storage areas is becoming more widespread as a means of protection from weather, keeping materials dry, and assisting in containing and eliminating dust and smoke which may be generated.

Scrap Preparation

Scrap materials, including foundry returns, are usually used in the as-received form. Where scrap preparation is required, the operations may involve any combination of the following:

1. Cutting to size by flame torch, shear or by breaking.
2. Cleaning by degreasing, steam or by shotblasting.
3. Burning of surface coatings or oils in a confined chamber or in the open air.
4. Drying or preheating.

With the exception of the cutting operations, scrap preparation is not widely performed for cupola melting, or for top charged electric arc furnaces. For electric induction furnaces and side charged arc furnaces, a greater degree of preparation is necessary to obtain dry scrap of the proper size.

Furnace Charge Preparation

The methods of makeup and handling of melting furnace charges vary widely from completely manual systems where all materials are hand shoveled or carried, to highly mechanized systems where one man can control the handling, weighing, and loading of all raw materials. Charge makeup for the cupola is more complex than for electric furnaces, because of the necessity of using coke and large quantities of flux.

Charges are normally loaded directly into the furnace charging bucket, skip, or similar container. The prescribed combination of metallics, flux and coke (for cupolas) is weighed either before loading or while loading.

IRON MELTING

Four types of melting furnaces represent over 98% of the installed melting systems. The following table, from a 1968 United States Department of Commerce[1] study, shows the distribution of melting furnaces in the iron foundry industry.

Iron Foundry Melting Furnaces - 1968

Furnace Type	Number Installed	Percent of Total
Cupola	1,232	89.5%
Electric Induction	73	5.3
Electric Arc	42	3.1
Other Types	29	2.1
Total	1,376	100.0%

The furnace census does not show the number of reverberatory furnaces in use, but it would be expected that they constitute the majority of the 2.1% indicated as "Other Types." Despite the low incidence of use, this method of melting is of interest because of its reported low emission of particulate matter, and its increasing use in small foundries.

The reverberatory furnace is heated by coal, natural gas or oil, while the induction and arc furnaces obtain their heat from an electric induction coil or an electric arc. In the cupola, coke is a portion of the furnace charge and the heat required to melt the iron is derived from the combustion of the coke in contact with the metallic and fluxing charge materials.

Exhibit III-7, Process Flow Diagram Melting Department, illustrates the most common flow pattern.

Cupola Furnaces

The cupola is a vertical furnace with a normally circular cross section which is charged alternately with metal, coke, and a fluxing material, to produce molten iron of a specified analysis and temperature. Many fundamental cupola designs have evolved through the years, two of which are widely in use at this time--the conventional refractory lined cupola and the more recent development, the unlined, water-cooled cupola.

For all cupola design, the shell is made of rolled steel plate. In the conventional design, an inside lining of refractory material is provided to insulate the shell. The unlined, water-cooled cupola utilizes a steady flow of cooling water on the outside of the unlined shell from below the charging door to the tuyeres, and an inside lining of carbon block below the tuyeres to the sand bed, to protect the shell from the interior temperature. Conventional lining is used at the charging door level and in the upper stack.

Illustrations of lined and water-cooled cupolas are shown in Exhibits III-8 and III-9. Exhibits III-10 and III-11 present approximate melt rates and gas volumes for lined and unlined cupolas.

The cupola bottom consists of two semicircular, hinged steel doors, supported in the closed position by props during operation, but able to be opened at the end of a melting cycle to dump the remaining charge materials. To prepare for melting, a sand bed 60 to 10 inches deep is rammed in place on the closed doors to seal the bottom of the cupola. At the beginning of the melting cycle, coke is placed on the rammed sand bottom and ignited, preferably with a gas torch or electric starter. Additional coke is added to a height of four or five feet above the tuyeres after which regular layered charges of metal, limestone and coke are placed on the coke bed up to the normal operating height.

The air blast is turned on and the melting process begins. As the coke is consumed and the metal charge is melted, the furnace contents move downward in the cupola and are replaced by additional charges entering the cupola through the charging door.

Combustion air is blown into the wind box, an annular duct surrounding the shell near the lower end, from which it is piped to tuyeres or nozzles projecting through the shell about three feet above the top of the rammed sand.

Blast air entering the cupola through the tuyeres contains 21% oxygen which combines quickly with the carbon in the coke as follows:

$$C + O_2 \rightarrow CO_2 + 175,900 \text{ BTU/pound mole}$$

The oxidizing zone in which this reaction occurs is designated the combustion zone. It is the zone of highest temperature and extends from the tuyeres to a level where the following reaction occurs:

$$C + CO_2 \rightarrow 2\ CO - 69,700 \text{ BTU/pound mole}$$

The reduction of CO_2 to CO starts before all oxygen in the blast air is consumed. The maximum CO_2 concentration is believed to be approximately 14%-18% at the boundary of the oxidation and reduction zones at a maximum temperature of $2,800^{\circ}$-$3,400^{\circ}$ F. Both reactions noted are reversible and proceed in both directions depending upon conditions at different levels. The reactions almost cease in the preheat zone as energy is used to preheat the charge materials and the gas temperature is lowered to the reaction temperature below which further reduction of carbon dioxide to carbon monoxide will not occur.[2] A pictorial description of a cupola reaction area is shown in Exhibit III-12.

The tap hole through which the molten iron flows to the spout is located at the level of the rammed sand bed. For continuous tap operation, the slag also is discharged through the tap hole and separated from the iron by a skimmer in the spout. For intermittent tapping, molten iron collects in the well with the slag floating on its surface, and a slag hole is located at the level representing the height of the maximum amount of iron desired to collect in the well. An opening is provided in the cupola shell 15-25 feet or more above the bottom plate for charging the cupola. The charging door opening varies in size according to the intended method of charging and the diameter of the cupola. The upper stack is extended sufficiently to pass through the building roof and provide the required natural draft. A spark arrestor is fitted to the top to reduce the hazard of fire.

Exhibit III-13 shows examples of typical material balances for lined and water-cooled cupolas.

Electric Arc Furnace

The direct arc electric furnace consists of a refractory lined, cup shaped, steel shell with a refractory lined roof through which three graphite electrodes are inserted. The shell is arranged for tilting to discharge the molten charge. Charging of the metal to be melted is accomplished by chuting through a door opening in the side of the shell for fixed roof furnaces, or by raising the roof and swinging it aside to permit the use of a bottom dump charge bucket for removable roof furnaces. Exhibit III-14 is an illustration of an electric arc furnace.

Foundry furnace sizes usually range in diameter from about 3'0" up to 12'0" with holding capacities of 500 pounds to 25 tons, and melting rates from 250 pounds to 12 tons per hour. In recent years, furnaces as large as 17'0" in diameter, holding 65 tons and with melting rates of over 20 tons per hour have been installed in production foundries.

Exhibit III-15 is a typical heat and material balance for an electric arc furnace.

Induction Furnaces

The induction furnace is a cup or drum-shaped vessel that converts electrical energy into heat to melt the charge. Unlike the electric arc furnace, no electrodes are required. Heat is produced by utilizing the transformer principle in which a magnetic field is set up when the primary coil of the transformer is energized. The magnetic field at a high flux density induces eddy currents in the charge which are converted to heat by the electrical resistance of the charge itself.

Heat develops mainly in the outer rim of the metal in the charge and then carries to the center by conduction until the metal is molten. The electrical energy is converted into heat by induction in two ways. In the channel induction furnace, the metal charge surrounds the transformer core, thereby forming a loop or channel. In the coreless induction furnace, the metal heated is both the core and the secondary coil. Furnace coils are water cooled to prevent heat damage.

Exhibits III-16 and III-17 are illustrations of channel and coreless induction furnaces.

The induction furnace lends itself to either continuous or batch-type operations and is used as a melting furnace or for holding or duplexing operations. Generally, the coreless furnace is better adapted to melting and superheating, whereas the channel furnace is better suited to superheating, holding, and duplexing, although it is also used for melting.

Induction furnaces are supported on a pedestal-type structure. A common arrangement contains pivot bearings for tilting the furnace for tapping. The entire furnace must rotate through about 100^{o} to empty the vessel.

The furnace top of a coreless furnace is normally level with the charging platform and the operating functions of charging and slagging are carried out on the platform.

Exhibit III-18 is a typical heat and material balance for a coreless induction furnace.

Reverberatory Furnace

The reverberatory type of fuel fired furnace is found in two types of applications in the iron foundry. The large, stationary reverberatory or air furnace is associated with malleable iron foundries, where it has long been used as a duplexing unit in conjunction with a cupola. These furnaces are generally powdered coal fired, although oil and gas are also used. They are not melters, but are used to receive molten iron from the cupola, and to refine and superheat it for pouring. These furnaces are long, rectangular units with arched or suspended roofs, generally fired from one end, and with waste gases exhausting into a stack from the opposite end. Temperatures of $2{,}900^{\circ}$ F and higher are reached in these furnaces. Holding capacities range up to 40 tons.[3, 4]

The second type of reverberatory fuel fired furnace is used for melting. It is generally small in size, up to two tons capacity, and tilts for pouring. Furnaces of this type are found in small foundries, where economical installations and low emission melting are desired.

Exhibit III-19 is an illustration of a reverberatory furnace.

Inoculation

Inoculation is a process used in the production of ductile iron or to improve the mechanical properties of castings.

In ductile iron production, inoculation serves to precipitate carbon in the iron in the form of disconnected spheroids. A matrix of low carbon ferrite forms which is required to make ductile iron of satisfactory quality. Because of economics and availability, magnesium is usually used for inoculation.

Pure magnesium can be applied, but a more common practice involves using nickel, copper or silicon with magnesium in alloy form. Magnesium impregnated coke is also popular. When the magnesium compound is added to the molten iron, the reaction is more or less violent depending upon the form of the magnesium.

Exhibit III-20 illustrates several methods of magnesium treatment.

MOLDING, POURING AND SHAKEOUT

Molding

Many molding materials and types of equipment suitable for the production of iron castings have been developed and are widely used today. Molding techniques found in current practice include green sand, dry sand, shell or hot box molding, full mold and the Rheinstahl process. Green sand molds are usually least costly of all molds to produce.

In general, molding sand is prepared by adding organic or inorganic binders and water to clean silica sand and mulling the material in a manner to insure that all sand grains are coated with the binder mixture. The prepared sand is then discharged from the mixer, or muller, and transferred to the molding area. In mechanized foundries, the transfer is usually effected by mechanical or pneumatic conveyor. Smaller foundries often use front end loaders, tote boxes, or wheelbarrows.

The typical molding operation is done with the aid of molding machines. The complete operation is often performed in two separate machines. Molding machines capable of molding cope and drag simultaneously in one molding cycle are often utilized.

Pouring

Pouring is generally done within a short time after the molds have been prepared to prevent drying of green molding sand. The molten metal is temporarily stored either in large refractory lined holding ladles, or in furnaces designed to maintain the tapping temperature, or to superheat the metal, from which it is tapped off as needed.

Shakeout

The hot casting is commonly separated from the sand on a heavy-duty vibrating screen. The sand flows through the screen openings to the return or shakeout sand system for transfer to the return sand bin of the sand conditioning system. The castings are removed from the shakeout manually, by hoist, or action of the vibrating screen to a cooling and sorting conveyor or to tote boxes.

Many foundries separate the casting from the sand manually, particularly those foundries which are not highly mechanized.

Exhibit III-21 illustrates a common process flow diagram for molding, pouring, and shakeout.

CLEANING, HEAT TREATING AND FINISHING

Cleaning and finishing of castings are the final operations performed in the foundry. Cleaning generally refers to the operations involved in the removal of sand and scale; sprues, gates, and risers; and fins, wires, chaplets or other metal not a part of the casting. The castings, after they have been separated from sand at the shakeout screen, are cooled in boxes or on a conveyor which moves them to the cleaning and finishing area. For gray iron castings, the gating system may be broken off by impact in the shakeout, or may be removed on a sprue removal section of the casting delivery conveyor.

Exhibit III-22 is a typical process flow diagram for cleaning and finishing.

Heat treatment of iron castings is performed for the following basic reasons:

1. For Gray and Ductile Iron

   Stress Relief - 1000° - 1250° F
   Annealing - 1250° - 1650° F
   Normalizing - 1650° F
   Quench and Temper - 1550° - 1600° F

2. For Malleable Iron

   Annealing - 1600° F

Generally, these treatments are carried out in batch-type or continuous heat treating furnaces which may be gas or oil fired, or electrically heated. Atmosphere control is sometimes used for the higher temperature treatments.

SAND CONDITIONING

Most of the sand used in the foundry molding operation is reused many times with the addition of binders and moisture for each use. The cost of new sand, its handling and storage space requirements, and additional cost for disposal of used sand make single usage of new sand impractical. Therefore, most foundries have effectively used sand collection and reconditioning systems.

In general, sand conditioning systems consist of the following:

1. Raw material receiving and storage
2. Sand mixing system
3. Prepared sand delivery system
4. Spill sand recovery system

Exhibit III-23 illustrates the sand conditioning process flow.

Reclamation equipment designed to remove the accumulated buildup of clay and carbonaceous material on the sand grains to extend the working life of molding sand is available. The use of such equipment often becomes a desirable economic alternative to the purchase of new replacement sand. Sand is often reclaimed by high production foundries with large molding sand requirements and by foundries located in areas where suitable molding sand is relatively expensive.

COREMAKING

Cores are normally made of silica sand, organic or inorganic binders, and a liquid to activate the binding material. The selection of the core formulation and process best suited to a particular application requires consideration of many factors including green strength, dry strength, porosity, core complexity, quantity of cores required, and raw material, equipment and production costs. The process flow diagram for coremaking is illustrated in Exhibit III-24.

The major coremaking processes in current use for castings are:

- Oil Sand Cores
- Shell Cores
- Silicate Bonded Cores
- Furan Cores
- Hot Box Cores

Oil Sand Cores

Oil sand cores are widely used although silicate and resin bonded cores are being used in greater numbers each year. Vegetable or mineral oils are commonly used as binders. Cereal binders and clay are often used in conjunction with core oils. The cereal binders, mostly derived from corn flour, are added to improve green and dry bond, decrease the oil required, and improve collapsibility of the core. Clay is often added in small amounts to increase the green strength.

Shell Cores

Shell cores for iron castings make use of round, clean silica sand. The resin normally employed for iron castings is phenolformaldehyde. Hollow shell cores are made by the investment process in a shell core machine, and small, solid cores can be made in a hot box machine.

Silicate Bonded Cores

Silicate bonded cores are made in a molding or core blowing machine, and set by the application of carbon dioxide in a manner that permits the gas to completely permeate the core. Since the storage life of silicate bonded sand is short when exposed to the air, due to absorption of CO_2, the mixed sand must be stored in covered containers.

Furan Cores

Furan air set cores employ resins made from furfuryl alcohol, ureas, and formaldehydes. The resins are mixed with core sand and phosphoric acid activator in conventional mixing equipment. Binders are usually converted from liquid to solid at room temperature.

Hot Box Cores

Hot box core resins include furfuryl alcohol, urea-formaldehyde and phenol urea-formaldehyde. The liquid resin is mixed with the core sand and activated in conventional mixing equipment. Binders are converted from liquid to solid by heat supplied by ovens, infrared lamps, dielectric ovens or heated core boxes.

PATTERN MAKING

Foundry patterns are normally made of wood or metal. Patterns for small production runs tend to be the former and for large production runs, the latter. Wood patterns generally have a shorter useful life, although they can be repaired more easily than the metal patterns which usually have a higher first cost. A large production requirement, however, often results in a lower pattern cost per mold if metal patterns are used.

Wood pattern shop equipment includes different types of saws, planers, joiners, lathes, edgers, routers and drill presses. Metal pattern making equipment includes typical machine shop tools.

IV - EMISSIONS GENERATED AND THEIR CONTROL

GENERAL CHARACTER OF EMISSIONS

Emissions of particulate matter, dust, fume, smoke, and gas are a by-product of most foundry processes and operations. The type, concentration, size and hazards of foundry emissions are tabulated in Exhibit IV-1 by foundry department and operation and are discussed in the following paragraphs.

Raw Material Storage and Charge Makeup

The handling, preparation, and charge makeup of basic foundry raw materials--scrap metal, coke, and limestone--produce moderate amounts of emissions. The storage of coke and limestone over extended periods results in degradation of these materials from the action of the sun, rain, and repeated freezing and thawing. Ferrous scrap corrodes rapidly. Subsequent handling during the makeup of furnace charges causes the limestone dust, coke breeze and rust to be released into the environment. Every conveyor transfer becomes a point where the emission control is desirable, as well as storage bins, weigh hoppers and the location where these materials are placed into charging buckets. Rehandling of coke results in additional degradation and, to a lesser degree, this is also true of limestone.

The preparation of metallic charge materials including the breaking and cutting of large scrap, removing cutting oil residue from machine shop turnings and borings in preparation of briquetting, and cleaning of return scrap represent additional sources of emissions. Breaking and cutting of scrap, and centrifuging of oily turnings and borings are a minor source of emissions. The removal of oil from turnings and borings by ignition results in smoke and vapors. The amount of emissions depends upon the quantity of oil remaining on the turnings and the method of removal.

Melting Department

The melting department is responsible for a large proportion of emissions, producing the need for emissions control equipment on cupolas, electric arc furnaces, preheaters and dryers. Emissions from coreless induction furnaces are usually insignificant due to the normally higher quality of the scrap charge and the fact that no combustion takes place in the unit. Channel induction furnaces also produce minimal amounts of emissions and are seldom provided with emissions control equipment.

Cupola

The cupola is the largest single source of difficult-to-collect emissions, producing fume, smoke, particulate matter, dust and gases. Concentrations are affected by the quality and quantity of charge materials, the use of techniques such as oxygen enrichment and fuel injection, the volume and rate of combustion air, and the melting zone temperature.[1]

Iron melting in a cupola produces heavy concentrations of emissions ranging in size from greater than 44 microns to less than 1 micron in a gas stream up to 2000° F. Concentrations are affected by the quality and quantity of charge materials, the use of techniques such as oxygen enrichment and fuel injection, the volume and rate of combustion air, and the melting zone temperature.

The range of concentrations of emission components reported by seven foundries are shown in Exhibit IV-2 and are in general agreement with those reported by Engels and Weber[2] shown below.

Chemical Composition of Cupola Dust

Component	Mean Range	Scatter Values
SiO_2	20%-40%	10%-45%
CaO	3-6	2-18
Al_2O_3	2-4	0.5-25
MgO	1-3	0.5- 5
FeO(Fe_2O_3,Fe)	12-16	5-26
MnO	1-2	0.5- 9

Exhibit IV-2 portrays the major components of particulate emissions from iron melting cupolas and the percentage by weight of the various materials determined by chemical analysis of the effluent of seven cupolas. The nine components can be grouped into three major categories: (1) metallic oxides, (2) silicon and calcium oxides, and (3) combustible materials.

The amount of metallic oxides occurring in cupola emissions is believed to be related to the presence of the respective metals in the scrap charge and their partial vapor pressures at the temperature of the cupola melting zone. All metallic oxides except those of iron indicate the presence of nonferrous contaminants or alloying additions in the metallic scrap. Thus, zinc oxide could result from the presence of galvanized scrap; lead oxide from terne plate, lead bearing steel, or red or white lead painted scrap; aluminum oxide from aluminum scrap, chromium, and copper; and cadmium oxides from chrome plated materials. Iron oxides are always to be found in cupola emissions, the concentration being dependent on such factors as scrap thickness, degree of surface corrosion, and temperature in the melting zone.

The oxides of silicon and calcium, representing the second category, derive from lining erosion, embedded molding or core sand on foundry returns, dirt from the scrapyard adhering to scrap, or from the limestone flux.

The third category of emissions, combustible material, includes coke particles, vaporized or partially burned oil and grease and other contaminants swept up the stack by the top gases. Certain other variables influence the amount of cupola emissions.

1. Blast rate. Specific blast rate, when increased, produces more emissions by entrainment of metallic oxides and mechanical dusts, such as coke and limestone. A portion of the entrained particles is filtered out of the gas stream by the burden, with a higher burden offering greater opportunity of particle capture. Emission rates are greater during burn-down, due in part to increased temperatures resulting in larger gas volumes, higher gas velocity, lower collecting ability of the smaller burden height, and greater formation of metallic oxide vapors in the melting zone. Furthermore, the vertical height of the reducing zone is shorter, with less potential for reduction of the already formed oxides.

2. Coke Rate. It is believed that cupola emissions vary directly as the percent of coke in the charge and some researchers have reported such a trend.[2] A degradation of the coke while weighing, charging, and moving downward in the cupola shaft will result in an increase of coke dust in the furnace. Therefore, any change in operating practice resulting in a decrease in the coke charge, including heating of the blast air, or injection of an auxiliary fuel, should have a beneficial effect on the amount of particulates emitted.

3. Afterburners. The use of an afterburner, properly designed and installed, decreases the quantity of combustible particles released to the atmosphere or control system. Sufficient oxygen must be provided through the charging door to permit complete combustion and the upper cupola stack must extend far enough to permit time for combustion before the particles

are exhausted to the atmosphere or to the emissions control equipment. Deficiency in either factor will tend to negate the potential advantage of the afterburner.

4. Oxygen Injection. Oxygen injection in the blast air tends to increase the quantity of particulate emissions by increasing the oxidizing nature of the melting area, and increasing the melting rate. Oxygen injection also increases the melting rate tending to offset the increase of emissions when considered as a function of metal melted.

5. Operating Practices. Operating practices have noticeable effects on emissions levels. The use of wood or paper products for igniting the coke bed results in smoke during this part of the operating cycle. Fluctuating burden height can result in higher emission rates. Coke and limestone require careful handling to limit degradation, and should be screened prior to weighing in order to limit the addition of dust to the charge. Shotblasting of foundry returns and cleaning of oil scrap will result in lower emissions.

Particle size distributions of cupola emissions for 19 installations are tabulated in Exhibit IV-3. A definitive relationship between size distribution and chemical composition of emissions has not been discovered in the literature. It is believed, however, that a high percentage of less than 5 micron particles coincides with a finding of substantial percentages of metallic oxides. Similarly, a high percentage of greater than 44 micron particles is believed to correspond to large amounts of SiO_2 from foundry returns and dirty scrap, and combustibles, including coke breeze.

Cupola design parameters have no discernable affect on emission type or quantity. Two trends are noted in recent test data:

1. Particulate emission rates from acid lined cupolas ranged from 9.5 to 37 pounds per ton with a median rate of 19 pounds per ton. For unlined cupolas the range was 7.5 to 66 pounds per ton with a median rate of 40.5 pounds per ton.

2. Those cupolas reported as using briquettes in the metallic charges all have emissions rates greater than average of all foundries for which emissions rates are available.

The data also indicate a significant correlation between emissions and blast rate for acid lined cupolas expressed by the formula:

$$E = .05 + .07\ B$$

where:

E = particulate emissions in pounds per ton of melt

B = specific blast rate in SCFM per square foot furnace area.

A plot of the data and the curve is shown in Exhibit IV-4.

Additional data for unlined cupolas indicate a significant correlation between emissions and coke rate and specific blast rate, expressed by the formula:

$$E = 57 - 6.6\ C + 0.1\ B$$

where:

C = metal to coke ratio.

The curve is shown in Exhibit IV-5.

Oxygen enrichment and natural gas fuel injection have been presented in recent years as techniques to reduce coke requirements, or to increase melting rates when using the same metal to coke ratio. These techniques have been partially accepted by the industry because of their substantial advantages but little research and development work has been done to date that establishes their effect on cupola emissions.

The available data are inconclusive but some show an increase in emissions resulting from oxygen enrichment. Other data however, indicate that although total emissions are increased, the improvement in the melting rate with oxygen enrichment results in a slightly lower emission rate per ton of metal melted. Additional testing is required to definitely establish the effect of oxygen enrichment on emission levels.

Chemical analysis of the metallic oxides in the cupola emissions for one cupola, with and without oxygen enrichment, is shown in the table on the following page.

Metallic Oxide Content of Cupola Emissions with and without Oxygen Enrichment

Metallic Oxide	With Oxygen Enrichment	Without Oxygen Enrichment
MnO	1.0%	1.0%
PbO	5.0	3.0
ZnO	35.0	28.0
CuO	1.0	1.0
FeO	46.0	48.0
SiO_2	11.0	18.0
SnO	1.0	1.0
Total	100.0%	100.0%

The tabulated data show little change in the content of iron oxide for the two operating conditions. It is reported that a visual examination of the plume verifies that the emission rate is higher with oxygen enrichment. Particle size distribution data were not obtained for this test program.

Several research programs are currently in progress to determine the effects of natural gas injection as a replacement for part of the coke charge. The results of one such program[2] are shown below.

Burner Height Inches	Coke Replaced with Gas Percent	Production Tons/Hour	Emissions Pounds/Ton Melt
-	0%	14.8	67.8
50	30	20.1	57.1
50	40	20.3	58.5

The emission rate of 67.8 pounds per ton reported for the control condition with no coke replacement is several times higher than shown in Exhibit IV-4 for a specific blast rate of 272 CFM/SF. Two special conditions, one inherent in the test program and the other a factor of weather conditions, could account for the discrepancy.[3]

The injection of other hydrocarbon fuels including coal and fuel oil has been reported in the literature. Less importance is attached to these efforts than the injection of natural gas, and no data pertaining to the effect of these fuels on emissions have been reported.

Electric Arc Furnace

The number of electric arc melting installations in iron foundries is relatively small, with less than 50 known to exist in 1959, and approximately 200 in 1969.

The emissions from iron melting in the arc furnace come from two principal sources--the burning or vaporization of combustible materials which are in the charged raw materials, and the burning of the electrodes and some of the charge metallics during meltdown. In both cases, the greatest evolution of gases occurs during the early part of the cycle, when meltdown takes place and when the electric power consumption is highest. Although the type and quantity of effluent from combustion of impurities in the charged materials is highly variable depending on the nature and cleanliness of these materials, the gases produced from combustion of the electrodes are a known and comparatively constant and calculable source of emissions. Approximately 9-11 pounds of electrodes are consumed per ton of iron melted, producing approximately 30 pounds of CO and CO_2 gases, plus 150 pounds of N_2 from air induced into the furnace. Additionally, a quantity of the metallics, principally iron, is oxidized and emitted as oxide fumes.

The electric arc furnace produces moderately heavy concentrations of particulates. From 50% to 80% of the total particles are less than 5 microns in size when melting iron. The gas stream is well over 2000° F, requiring cooling by infiltrated air or water sprays.

The size distribution of particulate matter and chemical analysis of the effluent from three electric arc furnaces are given in Exhibit IV-6. Emission rates are tabulated in Exhibit IV-7 for 19 acid brick lined arc furnace installations with capacities from 2 to 25 tons.

The wide range of emissions rates, from 4 to 40 pounds per ton of charge metal, and the lack of correlation with furnace size indicate that the rate at which emissions are produced is relatively independent of these factors. A slight trend exists toward a relationship between the rapidity with which melting occurs and the rate of emissions produced, indicating that high power inputs to produce short melt cycles will also produce higher emissions. This conclusion is further verified by the relationship depicted in Exhibit IV-8, in which the concentration of heavy rate of emissions is in the early or meltdown part of the cycle. The less time devoted to the holding or refining period, the more concentrated the emission rate will be during the cycle.

Induction Furnace

Induction melting produces light concentrations of effluent consisting of fume, smoke, and oil vapor. The smoke and oil vapor usually derives from small amounts of cutting oil adhering to the steel or iron scrap.

Coreless induction furnaces used as holding or superheating furnaces charged with molten iron only emit approximately 1.5 pounds of emissions per hour per ton of process weight and therefore are rarely provided with emission control equipment.

Reverberatory Furnace

The reverberatory or air furnace for melting or duplexing produces comparatively light to moderate concentrations of emissions in the range of 1 to 3 grains per standard cubic foot. Combustion occurs within the furnace but the gas or oil fuel is burned in highly efficient burners above the metal bath. Smoke, fume and fly ash are produced in this type of furnace. The smoke results from combustion of oil on the scrap and other combustible materials in the charge. Fume, mostly metallic oxides, appears in the effluent, as it does in any melting furnace, and is the result of nonferrous contaminants in the charge material, vaporized along with a portion of the iron scrap in the molten bath. The concentrations are related to the partial pressures of the oxides at the melting temperature.

Preheaters

Preheaters serve to raise the temperature of charge before it goes into an induction furnace. As a result, electrical efficiency and melting rates of the furnace are increased and melting time is reduced. Preheating also produces a clean, safe charge because water, oil, emissions and other nonmetallic contaminants are evaporated or burned off.

Preheat equipment includes a cover, base, bucket, combustion chamber, burner and fans.

The type and concentration of emissions found in preheaters are similar to that found in induction furnaces without preheaters.

Inoculation

The practice of producing ductile iron by ladle inoculation of molten iron with magnesium, or other light metals which produce similar effects, accounts for about 10% of total iron tonnage cast. The treatment agent is generally a form of magnesium which can be introduced into the molten iron to produce the desired effect. Exhibit IV-9 illustrates the various methods by which this can be accomplished.

The reaction produced during the inoculation process is a violent one since magnesium vaporizes at a temperature below that of molten iron. The degree of the violence varies with the form and method of introduction of the magnesium. Because of this, only a relatively low percentage of the magnesium which is introduced is actually involved in the reactions which produce ductile iron, with the remainder being vaporized and expelled as a gaseous fume. The actual yields vary from as low as 15% to high as 80%, depending on the inoculating agent used and the rapidity with which it is added to the iron bath. The yield factor which is most generally accepted is about 35%.

Magnesium is the principal agent causing emissions during inoculation, since the alloying materials which are used as carriers of the magnesium either dissolve in the iron or oxidize to form slag. A major exception to this is the use of magnesium impregnated coke which evolves CO and CO_2 gas as well as MgO fumes. The boiling point of magnesium is about 2,025° F, which is well below the temperature of molten iron and which accounts for the violence of the reaction which takes place. The magnesium in the inoculant is used up in three ways:

1. Reaction with any sulfur present to form MgS, which becomes part of the slag. Although iron which is to be used for ductile iron production is generally pretreated with a basic material such as Na_2CO_3 or $CaCO_3$ to remove sulfur, there is usually 0.02% to 0.03% of the sulfur remaining. This will be effectively eliminated by the magnesium, using about 0.5 pounds of magnesium per ton of iron.

2. A small quantity of magnesium will dissolve in the iron, to the extent of about 0.04%. This amounts to about

0.8 pounds of magnesium per ton of iron.

3. The remaining magnesium will boil off, forming MgO upon contact with the air. The amount of magnesium which is added will vary from 0.12% to 0.30% of the iron treated or from 2.4 to 6.0 pounds of magnesium per ton of iron. Deducting the 1.3 pounds of magnesium which was consumed by sulfur reaction or dissolved in the iron leaves from 1.1 to 4.7 pounds of magnesium per ton or iron treated to form MgO fumes. This will result in from about 2 to 8 pounds of MgO fumes generated per ton of iron treated.

The fumes from the inoculation process will be largely MgO, with this material accounting for from 60% to 80% of the total, depending on the form in which the magnesium was introduced and the violence of the reaction. The more violent reactions, particularly when silicon-magnesium alloys are used, will also produce SiO_2 particles in the emissions. Iron oxide, as Fe_2O_3, will also be found in the emissions and will constitute the second most important material present, after MgO.

Particle size of the emissions will be fine for the MgO and Fe_2O_3 portions with the silica and alumina particles generally of larger size. These particles are under one micron in size and are difficult to collect, requiring the use of fabric filters or high energy wet scrubbers.

The reported results from the inoculation station of a large gray and ductile iron foundry are as shown on the following page.

Iron Treated	-	30 Tons per Hour
Inoculant Added	-	20-22 Pounds per Ton Iron
Inoculants Used	-	Soda Ash MgFeSi-(10% Mg) 75% Fe
Emissions Produced	-	100 Pounds per Hour 3.3 Pounds per Ton Iron
Emissions Analysis	-	32.0% MgO 18.7% Fe_2O_3 9.5% CO_2 4.2% SiO_2 2.5% S 1.1% C 0.6% CaO Balance Na_2O

This station was used for ductile iron inoculation, desulfurization and ferrosilicon inoculation, which explains the presence of such elements as sulfur and calcium in the catch. The amount of magnesium in the inoculant was 2.25 pounds per ton of iron treated. At a yield of 35%, this resulted in 1.45 pounds vaporized, giving 2.4 pounds per ton of MgO. This amounts to 73% of the emissions actually captured.

Molding, Pouring and Shakeout

Molding

The molding operation is not a major contributor to foundry emissions. In green sand molding, the moisture in the sand acts as a dust suppressant. Small quantities of dry parting compound are emitted when the mold halves are dusted with this material. Liquid partings used to prevent molding sand from sticking to metal patterns or match plates have a kerosene base. When sprayed on the patterns, a portion of the vehicle vaporizes, and the solids such as stearic acid are sprayed into the air in the immediate environment. Sea coal is also used as a mold spray and is released into the atmosphere. Concentrations are light, approximately one grain per standard cubic foot.

Molding sands consist of silica, zircon, olivine, chamotte, and occasionally other mineral grains bonded with clay, bentonite, portland cement, plaster of paris, petroleum residues and bitumens. Additives are often added as cushioning materials, with such materials as sea coal, pitch, wood flour, silica flour, perlite, ground cereal hulls and chemicals in common use. Binders and additives used to improve the strength, molding properties, and casting properties of sand also contain amounts of combustible materials which form gas which evolves during the pouring and cooling of molds.

Green molding sands, which are most commonly used in iron foundries, may contain the following additives.

Additive	Amount by Weight
Wood flour	0.5% - 2.0%
Sea coal	2.5% - 8.0%
Cereal binder	0.5% - 1.0%
Silica flour	0.0% -15.0%

Pouring

Emissions from the pouring operation are much more severe than molding and are usually more difficult to capture. The hot metal, when poured into the mold, first ignites and then, as oxygen in the mold is exhausted, vaporizes such materials in the sand as sea coal, cereal and synthetic binders, and core binders. Steam is formed in green sand molds from the moist sand and in the full mold process, the complete pattern is consumed. Emissions are affected by the quantities of the different source materials required to produce satisfactory castings.

Most of the emissions are steam, vapor, and smoke with a smaller percentage of particulate matter. In the case of the full mold process and many of the synthetic binders, the emissions such as hydrogen chloride and methyl chloride are toxic, and only the low concentrations per mold, coupled with general foundry ventilating systems, prevent potentially serious physiological reactions in molders, pouring crews and shakeout men. The concentration of smoke, fume, and vapors is related to the hot metal temperature, length of time between pouring and shakeout, and the quantities of binders, moisture and parting compounds required to make a satisfactory mold.

The effect of molten metal during pouring is to vaporize the volatile materials and the water contained in the molding sand adjacent to the mold cavity. Although this effect decreases rapidly as the distance from the cavity increases, the gases formed are forced through the molding sand and vent holes and are expelled into the surrounding atmosphere. The nature of these gases is illustrated in Exhibit IV-10. The combustible portions of the gases are relatively high, consisting of from about 4% for dried molds to as high as 76% for molds with a high percent of cereal and bentonite. The H_2 in the combustibles comes from decomposition of water vapor, while the CO comes from combustion of organic materials.

The volume of gas formed is illustrated in Exhibits IV-11 and IV-12, for various mold materials. Gas evolved ranges from 200 to as high as 700 cubic feet per cubic foot of sand at 1,800° F. Only a small portion of the sand adjacent to the sand-metal interface approaches this temperature and gas formation drops off rapidly as the distance from the interface increases. Although relatively small amounts of particulates are involved, the toxicity of the unburned combustibles makes collection a desirable factor. The high temperatures associated with pouring often result in burning of gas as it leaves the molds. This afterburning is desirable to completely convert the combustibles to CO_2 and water vapor and to eliminate explosion and toxicity hazards, particularly if the mold contains oil sand cores.

Examples of toxic emissions are carbon, styrene, low molecular weight polystyrene, ethylbenzene, methyl chloride, chlorine, hydrogen chloride and decomposition of evaporative products in addition to CO, CO_2 and H_2O.[4]

Shakeout

At the shakeout, the action of separating castings from the mold brings the hot casting into contact with moist and cooler molding sand originally located away from the mold cavity.

The result is the creation of additional smoke, steam and vapor of the same type emitted during the pouring operation. Concentration of the emissions is momentarily high, over three grains per cubic foot, but the casting is cooler than the molten metal while pouring allowing the sand to be quickly separated from the casting. The emissions are often able to be contained and removed through the use of ventilated hoods.

Cleaning and Finishing

Cleaning and finishing operations produce emissions less troublesome than other foundry processes. Emissions are generally larger and easier to capture and separate from the airstream though concentrations can occasionally exceed three grains per standard cubic foot. Particle sizes are as large as five to seven microns and their concentrations are dependent upon type and surface speed of the grindstone and the amount of pressure exerted by the grinder. Chipping operations produce such large particles that control of the effluent is not required. Abrasive shotblasting produces high concentrations of metal particles, sand dust, and broken shot but modern blast machines are provided with high efficiency fabric filters designed for the purpose. The concentration of these emissions is a function of the quantity of embedded sand on the castings, fracture strength of the shot, and length of time in the blast cabinet or room. Sand blasting, now rarely used, produces high concentrations of sand dust with concentrations related to air pressure, blast sand characteristics and length of time required for cleaning.

Effluent from annealing and heat treating furnaces is minimal except when the castings have previously been oil quenched. Concentration of the resulting smoke is a function of temperature and amount of oil residue on the casting surfaces.

Painting is infrequently done by foundry departments. Effluent from this operation consists primarily of vapors from thinners and concentrations depend on the type and quantity of the volatiles.

Sand Conditioning

New molding and core sand are ordered to a desired screen test for specific use but always include some fines. The escape of fines into the atmosphere varies with the method of handling. Closed systems such as pneumatic conveyors release only small amounts and are provided with exhaust connections at the inlet and the receiver. Systems using belt conveyors and bucket elevators release fines and dust at most transfer points between conveying units.

Many smaller foundries unload and transfer sand to floor level bins manually, or with front-end loaders. Load and unload points are generally uncontrolled. The handling of conditioned molding or core sand presents fewer problems than new sand because of the moisture content and binder additives. Control equipment and hoods at transfer points are generally not required.

Shakeout or return sand produces more emissions because it has been partially dried from contact with the hot metal. Introduction of fresh spill sand from the molding floor and excess prepared sand helps considerably in cooling, moistening and decreasing dust and fines from being emitted at conveyor transfer points. It is considered good practice to enclose the transfer points and provide exhaust connection at these locations and also at the vibrating or rotating screen and the return sand storage bin.

Moderate concentration of fines, in the range of one to three grains per standard cubic foot, dust and binder materials are emitted at the sand mixer. Concentrations are substantially increased if the muller is equipped for sand cooling. This is accomplished by directing a blast of cooling air either over or through the sand while it is being mixed. The air blast entrains small particles and must be exhausted to a control device to separate the particulate matter from the air blast.

Coremaking

Emissions resulting from coremaking operations are generally in the form of fume and gas, the type and amount depending on the nature of the core mix and the coremaking process. The core mix is typically comprised of silica sand, binder and moisture. Sand emissions are light, under one grain per standard cubic foot. The binders used in coremaking include linseed oil, core oil, wheat flour, sulphite, pitch, oilless binders, resins, silica flour, fireclay, wood flour, iron oxide, bentonite, and silica sand.

Core binders that generate a considerable volume of gas on pouring of the mold are undesirable. A typical core mix for malleable iron castings might be as follows:

Sand	Cereal	Moisture	Oil	Binder
92%-98%	.75%-1.25%	0%-5%	0%-1%	0%-.5%

Core mixes for gray iron castings vary greatly according to the general size of the casting and the specific application for the part. The rate of gas volume generated in a core during the curing process is largely a function of baking time. Exhibit IV-13 illustrates the effect of baking time on the volume of gas generated at various baking temperatures. A review of the curves quickly points out that the gas content is reduced by baking at higher temperatures.

Resinous binders, normally used in shell molding processes, cause various hazards. The decomposition of the products is extremely toxic. Dermatitis is the principal effect caused by an excess of free phenol, formaldehyde, hexamethylenetetramine, or alcohol. The extent of the hazard depends upon the specific agent and the tolerance level for that agent. Phenol, for example, can cause dermatitis and do organic damage to the body at levels exceeding five parts per million. Formaldehyde is a nuisance at levels exceeding five parts per million. Hexamethylenetetramine can cause skin irritations with direct contact.

Other toxic and irritating materials include furfuryl alcohol, ethyl alcohol, methyl alcohol, urea, carbon monoxide and silica dust. These can be released during shell operations. Each has varying minimum levels of concentration before its toxicity or irritation are critical or a nuisance. Ventilation becomes the important factor in minimizing these hazards.

The sand-to-oil ratio has a bearing on the volume of gas generated in a core during pouring. The effect of sand-to-oil ratio on the amount of core gas given off during pouring is illustrated in Exhibit IV-14. The relative amounts of gas produced by various core binders is given in the table. Composition of gas has not been determined.

Core Binder	Cubic Centimeter Gas per Gram
Linseed	380 - 450
Petroleum	350 - 410
Urea Resins	300 - 600
Cereal	550 - 660

Inventory of Foundry Emissions

An analysis of cupola and electric furnace emissions and the factors affecting the rates of emissions shows that an average of 20.8 pounds of particulate emissions are produced per ton of metal melted in an iron foundry cupola, and that an average of 13.8 pounds of particulate emissions per ton of metal melted results from direct electric arc furnace iron production.

Exhibit IV-15 shows the total estimated particulate emissions generated by melting operations in foundries using cupolas and direct electric arc furnaces in 1969. The exhibit shows total quantities for each of nine geographical regions and the nationwide totals based on the molten iron production for the year and the above emission rates. Based on a survey of iron foundries, considering the number and capacity of furnaces equipped with control systems, the effectiveness of the control systems, and the number of uncontrolled furnaces, it is estimated that 75% of the particulate emissions generated are presently being released to the atmosphere.

Exhibit IV-15 also shows estimated quantities of carbon monoxide generated and emitted. The first estimate is based on an average cupola operating with a 7/1 coke ratio, using coke with a carbon content of 91%, and with 11.6% carbon monoxide in the top gas. Under these conditions, 276 pounds of carbon monoxide is generated per ton of metal melted.

The amount of carbon monoxide emitted to the atmosphere is dependent on a number of factors including the temperature of the top gas, the availability of infiltrated air to provide oxygen for combustion, the completeness of combustion, and the percent of the total time that burning of the carbon monoxide occurs. With sufficient oxygen from the infiltrated air and with constant combustion, the carbon monoxide content should be completely burned. Several factors tend to work against this ideal condition, including the flame being extinguished by each charge addition, lack of immediate reignition either without an afterburner, or with an improperly directed flame from an afterburner, varying carbon monoxide content precluding constant combustion, and variable air supply. A conservative estimate of 50% combustion efficiency has been applied to the quantities of total carbon monoxide generated to obtain the estimated weight of this gas emitted into the atmosphere.

The results of the calculations for emissions from melting operations can be summarized as follows for 1969 nationwide production levels:

Total castings produced	16,614,000 Tons
Total molten iron produced	24,367,000 Tons
Total particulate emissions generated	243,000 Tons
Total carbon monoxide generated	2,924,000 Tons
Total particulate emissions emitted	182,000 Tons
Total carbon monoxide emitted	1,462,000 Tons

The above data are derived only from cupola and electric arc furnace operation. Emissions from other melting equipment including induction furnaces and reverberatory furnaces are negligible, not only because of conditions inherent to these types of furnaces but also because generally cleaner scrap metal is used for furnace charges and a relatively small percentage of the total iron is melted in these furnaces. Preheating of less clean scrap for charging into induction furnaces will add significantly to the emissions inventory only when the process is substantially more widely used than it is now. At its present level of application, preheater emissions are also negligible.

Emissions from non-melting foundry processes, with a single important exception, are often controlled as a standard practice, have the most effect on the foundry environment, and are released to the atmosphere in lesser quantities than the cupola and electric arc furnace emissions. The concentration of these emissions at their source can be substantial as in the case of the shakeout, abrasive cleaning, and grinding, but the particles emitted are often large with a relatively high settling rate. The portion of the particulate matter escaping the normal collection ductwork tends to settle out within the foundry building.

The non-melting emissions posing the greatest current problem are those resulting from coremaking. A minor problem existed in the past when practically all cores were made from oil sand. This type of core, however, is thermally cured in a core oven, and the emissions are relatively easy to capture from the core oven stack for afterburning. The use of organic chemical bonding agents, that are becoming more and more widely used, intensifies the problem since these produce emissions extremely difficult to capture due to their method of application.

Molds or cores made from air set sand are often set out on the foundry floor or racks while the sand sets. The local environment in this situation is often extremely poor. Not only is it difficult to capture the emissions over a large floor area, but the dilution of the gaseous emissions by the air makes the resulting mixture difficult and expensive to incinerate in any type of afterburner.

The situation in many foundries for thermally cured chemical binders when making shell or hot box cores causes similar problems for the local environment as well as afterburning. The resulting odors can be detected beyond the foundry property in many cases.

Exhibit IV-16 shows estimated nationwide quantities of particulate emissions from non-melting operations by geographical regions. The exhibit shows that an estimated 1,504,000 tons of particulates were generated, and that 76,600 tons of the total are emitted into the atmosphere.

CONTROL OF FOUNDRY EMISSIONS

The current state of the art of foundry emissions control does not fully satisfy the needs of the industry. On a purely technical basis, virtually all particulate and most gaseous emissions can be controlled. However, the cost of such control for several basic foundry processes may be beyond the present financial ability of the small and medium foundries, which comprise approximately 90% of the industry.

The emissions more difficult to collect are by and large those with large concentrations of very fine particles five microns and smaller. Conversely, the emissions easier to collect are those consisting entirely of large particles.

The problems arising from each type of foundry contaminant and the techniques of pollution control vary with the nature of the specific situation. Of all techniques available to control foundry pollutants, emission collection equipment systems are the most significant. These systems, which include dry centrifugals, wet collectors, fabric filters and electrostatic precipitators, vary widely in design, capabilities, cost and application. A tabulation of different emission collection equipment designs and their particular application to foundry processes is shown in Exhibit IV-17.

In addition to the many dust collection equipment systems which are in use, a variety of types of hoods, ventilating and exhaust systems and various other techniques are employed to capture or exhaust foundry emissions.

Exhibit IV-18 presents a summary of control equipment on gray iron foundry melting furnaces and a review of the collection efficiencies of the control equipment is given in Exhibit IV-19.

Raw Material Handling, Preparation and Charge Makeup

Few fixed emission points exist in typical yards where control can easily be applied; however, most of the emissions which come from these areas are dusts of relatively large particle sizes which settle readily. In a few cases, ventilation systems and dry centrifugal collectors have been installed in the charge makeup area, when it is located inside an enclosed building.

The one area which has been receiving attention in recent years involves those foundries in which metallic charge materials are either burned to remove nonmetallic coatings or accompanying nonmetallic debris, or are preheated to remove moisture or oily coatings. Since these operations are almost always performed in a fixed combustion unit of some type, emission control systems are relatively easy to apply. Medium energy wet collectors have been used where oil fumes were present, and dry centrifugal collectors were applied where dry dusts were to be collected.

Cupola Melting

It is estimated that approximately 360 iron foundry melting systems in the United States are currently equipped with some type of air pollution control equipment, ranging from wet caps to fabric filters, wet scrubbers, and electrostatic precipitators. In fact, every known method, from simple spark screens to complicated systems such as electrostatic precipitators, has been tried with varying degrees of success. Although selection of cleaning equipment varies with the purpose of the installation, recent attention has centered on those techniques which have been most successful in high efficiency control of emissions, such as high energy wet scrubbers and fabric filter baghouses.

The problem of selecting gas cleaning equipment for cupolas depends essentially on the degree of efficiency required, need to meet existing pollution codes, and the economic factors of capital and operating costs.

Wet caps, dry centrifugal collectors, wet collectors, fabric filters and electrostatic precipitators are the different collection systems which have been used for cupola emission control.

Wet Caps

Approximately 95 gray iron foundries had cupola wet caps in 1967. These collectors are placed directly on top of cupola stacks and thus do not require any gas-conducting pipes and pressure-increasing blowers.[2] Wet caps are relatively simple designs and usually consist of one or more inverted cones surrounded by a collecting trough. Energy requirements are low and collection efficiency is best for particles 44 microns in size and larger. These systems are most practical in plants having an existing supply of low cost water and the ability to dispose of collected dust in sludge form.[5] Furthermore, some type of wet cap system is often employed in conjunction with high energy wet collector installations on cupolas.

The low efficiency of the wet cap has caused it to decline in use in recent years. Attempts are now being made to develop higher efficiency of wet caps with multiple spray sections.

Dry Centrifugal Collectors

This is a low energy unit designed for larger sized particles in light to moderate concentrations. In a cupola installation, ductwork and an exhaust fan to draw gases to the collector are required. These systems also necessitate capping the cupola and installing a cooling spray to reduce the temperature of exhaust gases flowing to the collector. Often, dry centrifugal units are used as precleaners of hot blast cupola top gases prior to feeding into a recuperator. Furthermore, this type of collector is an integral part of most high efficiency emission collection systems. In 1967, approximately 15 gray iron foundries had dry centrifugal installations which were not part of a larger cupola emission collection system. The low efficiency of the dry collector has resulted in almost no new installation on cupolas in recent years, unless they were part of a larger system.

Wet Collectors

Several different medium and high energy designs have been applied on cupolas. A wide range of capacities and collection efficiencies is available. These systems are usually used where moisture and/or high temperature are present in the emission. A complete installation requires ductwork, an exhaust fan and capping of the cupola. As with wet caps, these systems are most practical where low cost water and sludge disposal equipment are available.[5, 6] Although only 30 gray iron foundries had cupola wet collectors in 1967, recent trends indicate that installations of this type system are increasing more rapidly than any other.

Fabric Filters

When cupola collection efficiencies of 99% or higher are required, the fabric filter is the system type often selected. Although various fabric materials are available, glass fabric is typically chosen because of its resistivity to high temperatures. Complete installations may include numerous components such as a baffle, raised cupola stack and lid, ductwork, exhaust fan, spray coolers and other items in addition to the fabric filter unit. Another type of installation involves using heat exchangers instead of spray coolers. Fabric filter units can be installed to handle more than one cupola if desired.[6] Approximately 39 gray iron foundries were equipped with fabric filters on cupolas in 1967.

Electrostatic Precipitators

Rare applications of these systems have been made on cupolas. Excessive costs, operating and maintenance problems have limited their use. Only one gray iron foundry was reported to have a cupola electrostatic precipitator installation in 1967. Additional installations have been made in the past few years.

Afterburners

In cupola installations, afterburners or gas igniters can be employed for burning the combustible top gases, thereby reducing the opacity of particles and CO discharged from the stack, and for eliminating potential explosion hazards from cupola gases. Afterburners are usually located just below or opposite the charging door.[6]

Preheaters

Burning of unburned products of combustion can also be accomplished at times with a type of blast air preheater which burns exhaust gases from the cupola. Not only is thermal efficiency of the cupola capable of improvement, but the preheater acts as a settling chamber for collecting coarse dust.[6]

Electric Arc Melting

A number of significant differences exist between the electric arc and cupola air pollution problem. First, the electric arc melting process and emissions problem are less complex. Second, since the average particle size of electric arc emissions is considerably smaller than that of the cupola, different collection objectives exist. Finally, more uniform electric arc operating conditions and lower emissions evolution tend to simplify the design of control equipment for this process.[8]

In 1967, approximately 24 gray iron foundries had some type of air pollution control equipment for electric arc melting processes, but the number of installations has increased substantially in the last few years.

Fabric Filters

Fabric filters are best suited for electric arc furnaces and have been most frequently applied. This is due to the extremely fine particle size of dust and fume emitted from electric arc furnaces. Complete installation of a fabric filter unit to the furnace includes ductwork, an exhaust fan to draw gases to the collector and a means of collecting the gases from the furnace.[6] Approximately 20 gray iron foundries had fabric filter installations on electric arc melting in 1967.

Wet Scrubbers and Electrostatic Precipitators

These collection systems are rarely used on electric arc furnaces. Wet scrubber limitations include the existence of too much fine dust and high energy requirements. Electrostatic precipitators can encounter exhaust volumes too low for their design requirements.[9] Four foundries were reported to have wet scrubber installations in 1967 on electric arc melting processes.

Furnace Hoods

Electric arc furnaces are also equipped with various types of hoods to capture pollutants.[10] Arrangement of electrodes and gear above the furnace top as well as the method of charging and operating largely determines the hood type applied. Often, some type of hood is used in conjunction with a collection unit.

1. Full Roof Hood - This type of hood is attached to the top ring of the furnace. It requires stiffening to prevent sagging at high temperatures and protection of electrodes to prevent short-circuiting.

2. Side Draft Hood - This unit is located on the side of the roof close to the electrodes to produce a lateral type of control. An overhead hood at the charging door is also often used with the side hood.

3. Canopy Hood - A canopy hood, located above the craneway, usually offers little interference with furnace operating procedure. Effectiveness of these units is limited due to equipment requirements needed to handle the large volumes of infiltrated air.[6]

Fourth Hole Ventilation

In this system, a water-cooled probe is directly connected to the furnace roof. The probe maintains a carefully controlled draft in the furnace body.

Snorkel

This technique is similar to the fourth hole ventilation method except that the extra hole serves as a natural pressure relief opening for the furnace.[8]

Electric Induction Melting

No combustion and only limited metal oxidation occur in this type of furnace and since relatively clean scrap is used for charge material, no serious emissions problem exists for induction melting of iron.

Induction melting produces light concentrations of emissions consisting of fume, smoke, and oil vapor. Control devices are usually not provided or required. The smoke and oil vapor usually derives from small amounts of cutting oil adhering to the steel or iron scrap, and can be eliminated by preheating prior to charging into the induction furnace.

The burning of oil residue on the scrap produces objectionable effluents requiring the use of emission control equipment. Afterburners and wet scrubbers on the preheater, either separately or in combination, are often used to reduce these emissions to acceptable levels.

Reverberatory Furnace

The emissions from this type of furnace come principally from the combustion of oil or gas fuel, plus some slag and iron oxide which is carried up the stack with the products of combustion. The older installations are exhausted into the atmosphere through a stack or chimney. Medium energy wet scrubbers with a 3- to 20-inch pressure drop and fabric filter bag collectors have been applied in a few cases.

The rotary reverberatory furnace has been only recently utilized in small installations in iron foundries. A small quantity of emission in the form of waste products of combustion and slag particles is given off. None of these installations has been equipped with a collector.

Inoculation

The original installations of inoculation stations either exhausted directly into the foundry building, or were equipped with a ventilation hood which then exhausted into the atmosphere. In recent years, ductile iron inoculation stations have been equipped with collecting hoods, or have been installed in enclosed rooms, and the resultant gases have been drawn off by means of an exhaust fan, into a dust collection unit. Medium energy wet scrubbers and fabric filter baghouses have been used for dust collection for ductile iron inoculation stations.

Mold Pouring, Cooling and Shakeout

Capture of emissions resulting from pouring and cooling of molds has been common for several decades for those high volume production foundry installations where finished molds are set out on continuous car-type mold conveyors, providing fixed locations for pouring, cooling, and shakeout operations. With this type of equipment, side draft hoods are often provided for the pouring area and side or bottom draft hoods at the shakeout, with the mold cooling conveyor between these two points fully hooded with sheet metal. Ducting is commonly provided from each area to a single control device, usually a wet scrubber or dry centrifugal collector.

Collection systems have been, and still are, uncommon for those smaller production and jobbing foundries where completed molds are set out on the foundry floor or on gravity roller conveyors, and where the pouring and cooling utilize a substantial percentage of the molding floor. The problem for this type of operation is related more to the cost of capture of the effluent with a minimum amount of infiltrated air, than to separation of the effluent. With pouring and cooling in nonfixed locations, and without hoods to capture the effluent, much of the air in the foundry would require handling at a prohibitive cost, due to the volume processed. Furthermore, large particles quickly settle out on the floor and machinery since the airflow is far below the minimum capture velocity. A partial solution to the problem in the pouring area has been provided in nonferrous foundries by a traveling vent attached to the pouring ladle bail, and ducted by means of flexible tubing and specially designed connecting ducts to a suitable emission control unit. This technique permits capture of effluent resulting from mold pouring with a minimum of infiltrated air. Additional venting is required during subsequent cooling, however, and this is not practical when the ladle is moved on to pour the next mold, with the result that significant emissions are still not collected. There is no reason why similar equipment could not be developed for iron foundries.

Large castings, such as automotive dies and machine beds, can be cast by the full mold process. Generally, no central pouring station is provided and the smoke generated is released directly into the foundry building, creating an industrial hygiene problem.

The current method for controlling the smoke is through the use of ventilating fans. A properly designed arrangement of fans and makeup air systems may produce a relatively clear shop environment, but as the smoke is exhausted from the foundry, an air pollution problem is created. The problem is further complicated by the fact that ventilating fans exhaust large volumes of low pressure air and are not designed to be connected to a duct and collector arrangement.

Sand Preparation and Handling

Processes such as mechanical sand handling systems and sand mixing or reconditioning equipment produce an emissions problem. Medium energy wet collectors are best suited for effluent control. Occasionally, fabric filters are employed only when dry sand conditions exist. Often, some type of hood is used to capture emissions in sand conveyor systems especially at transfer points. As with many other processes, ductwork and an exhaust fan are required in a complete collection system.[9]

Coremaking

The gases emitted from bake ovens and shell core machines are a serious problem and difficult to control. Usually these gases are permitted to exhaust to the atmosphere through a ventilation system. Sometimes, catalytic combustion devices are used on core ovens to burn gases to noncombustible analysis.

Other coremaking processes present a less serious air pollution problem capable of control. In core-blowing or core-shooting, fabric filters are usually selected if control equipment is desired. In rare instances, medium energy wet collectors are used. For core grinding, cotton or wool fabric filters and medium energy dry mechanical and wet scrubbers are frequently selected.[9]

Cleaning and Finishing

Dusts from gate and riser removal are generally controlled with local exhaust systems connected to dry mechanical collectors, medium energy wet collectors, or possibly cotton or wool fabric filters. Sometimes exhaust hoods are provided above the work station. Other cleaning processes such as abrasive shot-blasting and tumbling are commonly controlled with fabric filters or medium energy wet collectors. Applications of dry mechanical collectors are also made for abrasive cleaning processes.

Most of the trimming and finishing operations generate pollutants and require control. Chipping and grinding operations are normally provided with local exhaust hoods connected to either high efficiency centrifugals or fabric filters. Wet collectors are used if central sluicing systems are employed or where grinding exhaust is combined with other cleaning room operations.

Surface painting requires ventilation to reduce the hazard due to volatile materials being atomized in the air. Exhaust systems are generally used where dip painting is performed. Open tank installations are also provided with local ventilation hoods.[9]

Heat treating furnaces for malleableizing or for other treatments of iron castings present the usual problem of emissions from combustion of liquid or gaseous fuels. In most foundries, these are exhausted into the foundry building, or through a stack to the atmosphere. Medium energy wet scrubbers are an effective means of cleaning these exhaust gases, but have not been applied in many cases.

Miscellaneous Areas

Some of the non-manufacturing areas are sources of air pollution in foundries. These include the pattern shop and crating or boxing for shipping, where woodworking operations occur. Dry centrifugal collectors are commonly used to collect the wood dust and chips from these operations. Machine shops and metal pattern shops usually present minor problems of collecting the dust from machining or grinding of cast iron. Dry collectors are commonly used for this purpose.

COST OF EMISSION CONTROL SYSTEMS

Generally, all foundry emissions are expensive to control, and since the collected material has little or no value, its collection adds no value to the foundry's product. The installation and operating costs of control systems vary over a wide range.

The cost of an emissions control system depends on the following variables:

- Properties of emissions, including size distribution, density, chemical composition, corrosiveness, solubility, combustibility, and concentration.

- Difficulty of capturing the emissions in an air, gas, or water stream of moderate temperature and volume.
- Difficulty of separating emission particles from the captor medium.

Properties of the matter to be collected are generally fixed by the process and raw materials, although modification of the equipment could possibly alter the properties. Assuming them to be fixed for a given operation, the first consideration is the cost of capture. If the operation occurs in an enclosed and fixed location such as a melting furnace or oven, capture may be relatively simple and may be accomplished at low cost although emission collection and separation costs could be high. If the location of the operation is not fixed and occurs in the open, such as pouring of molds set out on the foundry floor, then capture is difficult and more expensive. In the latter case, with pouring emissions dispersed throughout the plant, much of the air in the building must be processed through the control system to collect the emissions. A system of this capacity would be expensive to install and operate.

The third factor of system cost is the difficulty of particle separation from the captor medium. Large, dense particles, such as metallic fragments from grinding operations, can usually be separated by the use of relatively low cost dry centrifugal collectors. Submicron-sized metallic oxide particles from a melting furnace, however, require more costly collection equipment such as high energy wet scrubbers or fabric filters.

The basic and auxiliary equipment costs are the main components of the total capital cost. These equipment costs varied on the average from 42% to 66% of the total capital cost. On an individual foundry basis, the ratio of equipment to total investment varies considerably. The following information illustrates the average ratios observed for cupola installations.

Equipment Costs as a Percentage of Total Investment Cost

Control System	Equipment Cost/Total Investment Average	Range
Wet Caps	42%	36% - 67%
Mechanical Collectors	55	36 - 79
Low Energy Wet Scrubbers	65	48 - 80
High Energy Wet Scrubber	66	48 - 85
Fabric Filter	65	41 - 82

The wide variance in the range of equipment cost as a percent of total investment is caused by several factors. The data represent installations at many foundries which have many different requirements. Some foundries had available space for the control equipment while others required some plant modifications to install the equipment. The age of the foundry affects the cost. In some new foundries, the pollution control equipment was designed as an integral part of the facility, while in old foundries, additional costs must be incurred for adaptation of facilities.

Cupola Melting

The approximate installed cost of control equipment is given in the following table:

Approximate Installed Cost, $/ACFM for Cupola

System	Cost
High Energy Scrubber	$6.50-$8.50
Low Energy Scrubber	1.75- 2.50
Fabric Filter	7.50- 9.00
Mechanical Collector	3.00- 5.00

The annual operating costs are given in the following table:

System	Approximate Annual Cost $/Ton	
	Above Charge Door Take-Off	Below Charge Door Take-Off
High Energy Scrubber	$2.10-$9.00	$1.00-$4.00
Low Energy Scrubber	.90- 5.00	.35- 3.50
Fabric Filter	2.00-10.00	1.00- 4.00

The wide range in operating cost is due to variations in cupola utilization. Foundries operating at 4,000 hours per year will approach the lower limit of the range and foundries operating at 1,000 hours per year or less will approach, and possibly exceed, the higher value.

Electric Arc Melting

The approximate installed cost of control equipment is given in the following table.

Approximate Installed Cost, $/ACFM for Electric Arc

Roof Diameter	Local Hood		Remote Canopy Hood	
	Intermittent Operation	Continuous Service	Intermittent Operation	Continuous Service
6 feet	$2.10	$2.50	$1.25	$1.85
8 feet	1.90	2.50	1.25	1.75
10 feet	1.85	2.35	1.25	1.70
12 feet	1.85	2.30	1.25	1.60
14 feet	1.80	2.25	1.25	1.60

Annual operating costs of fabric filters are given in the following table:

System	Approximate Annual Costs $/Ton	
	Canopy Hood	Local Hood
Fabric Filter	$2.90-$8.00	$1.70-$4.00

The range in annual costs, as in the case of the cupola, is due to variations in electric arc utilization. Furnaces operated at 4,000 hours per year will approach the lower limit and foundries operating at 1,000 hours per year will approach the higher value.

V - RECOMMENDED PRACTICE FOR TESTING PARTICULATE EMISSIONS FROM IRON FOUNDRY CUPOLAS(1)

by A.F.S. & G.D.I.F.S.

INTRODUCTION

The iron foundry industry has had many air pollution studies conducted on cupola emissions at their various plants. Of great concern to the industry and to the individual firms that have conducted such testing are the many varied and diverse test methods and test procedures used by the variety of independent organizations conducting such tests. The diverse methods and equipment used in performing such tests have made comparison and evaluation of results impractical or a near impossibility. Many of the tests conducted have shown marked inconsistencies between individual test runs by the same test group and also in comparing the results on the same system by different testing organizations.

A number of the procedures used in cupola testing suffer from obvious inadequacies when they are carefully scrutinized. Consequently, it has been deemed desirable and necessary that a recommended test procedure and testing method be made available to assist the metalcasting industry in achieving the maximum in emission control with the minimum of wasted and misdirected effort and expense. Since the industry is unique in the large, nonproductive investments needed to gain compliance with air pollution control requirements, it is especially significant that its emissions be evaluated by test methods and procedures able to produce consistently reliable results detailing these emissions, but do not unnecessarily and unfairly penalize the plant.

Particulate emission tests of cupola stack gases are done under varied conditions and in several different locations, depending on the test objective. Both location and objective influence the test equipment employed although the two usual purposes will be:

1) to determine nature and/or quantity of emissions released in the raw cupola gases

Note: The recommended procedure discussed in this section has, of this date, not been endorsed by any bodies other than A.F.S. and G.D.I.F.S. and is presented for information only.

2) to determine nature and/or quantity of emissions on the cleaned gas side of a control unit.

Raw gas test locations:

a) In cupola stack, above charging door. This is the most difficult location for testing. Gas flow is extremely uneven and the flow rate is relatively low; gas temperature is high - often 1200°-2200°F - and fluctuating; dust loading is extremely uneven because of channeling caused by indraft of much cold outside air drawn into the cupola stack through the charge door. This test location is necessary where a cupola has no control systems or has a wet cap type collector.

b) In inlet duct ahead of dust collector. This is an easier location if a reasonably straight duct run is available. Duct velocities and dust loadings are more uniform and confined in a smaller cross section. Normally gases will be cooled to 500°F or lower at the sampling point from evaporation of cooling water. The added volume of water vapor must be measured and considered in gas density calculations and dust loadings if reported in grains per standard cubic feet dry gas. Inlet and outlet samples should be supplemented wherever possible by using the catch as a check for the test data. Catch can be more readily obtained from dry collector types especially for a complete melting cycle.

c) Catch plus outlet loadings. Where dry collectors are employed, the entire test procedure is simplified by actual weighing of collected material. The higher the efficiency of the collecting device the more nearly the catch will represent the raw sample. Chances for error are diminished because of quantity of collected material available although it will be difficult to obtain accurate catch quantities except for a complete melting cycle - thus providing an averaging of the peaks and valleys of emission concentrations.

See comments for outlet loading under "Cleaned Gas Locations".

Cleaned Gas Locations:

a) After dry collector. Conventional dust sampling techniques will be satisfactory for such locations. Coarse particles will be removed by a dust collector so the importance of a large diameter sampling probe diminishes. Water vapor content of the gas should cause no condensation problems with 350° to 550°F gas temperatures. Collecting device in sampler can be influenced by intended analysis - gross weight, particle size distribution, chemical composition, particle count, etc.

b) After wet collector. Sampling problems are more complicated than after dry collectors because gas stream is saturated or nearly so. Close coupling of sampling components is essential and heating of the sampled air often required.
Exception: Wet cap type of collectors have too short a contact time to bring gas stream close to saturated conditions. Sampling after the collector will be questionable value unless gases are gathered in a discharge stack of several diameter lengths.

In recognition of these differences in purpose and location for testing emissions the following procedure is divided into three sections.

Section I deals exclusively with sampling raw particulate emissions in the cupola stack.

Section II deals exclusively with sampling raw particulate emissions in the inlet duct connecting the cupola to the dust collector.

Section III deals exclusively with sampling cupola gases after they have been cleaned.

REASONS FOR SAMPLING A CUPOLA

Basically sampling is done for three reasons:

1) to determine if a collecting device is of a high enough efficiency so that its effluent does not exceed a pre-determined level.
2) to meet regulatory requirements that specify a minimum efficiency of removal of particulate from the gas stream, expressed as a percentage of uncontrolled emission.
3) to obtain information regarding particulate emission which will be used for designing gas cleaning devices.

Officials of local, regional or state regulatory bodies should be consulted prior to testing except when the testing is being done for purely informational data for the cupola owner or operator.

If source testing is being done to determine compliance with legal requirements the appropriate control officials should be consulted. If the control body has experience and is equipped to perform cupola testing, they may wish to perform their own tests to determine compliance.

Generally control bodies will not accept the results of tests performed by the owners, operators or vendors of collection devices unless standard procedures were followed and test data and reports show evidence that experienced personnel conducted the tests.

In most cases it will be necessary for the owner or operator of a cupola to employ the services of an organization capable of performing these tests. When this is done the control authorities should have given prior approval of the testing organizations capabilities and acceptability of their test results. In any event, it is advisable to notify the proper authorities in advance so that they may have on site observers present if they so desire.

The foundryman should select a testing organization with proven capability, a good reputation and in whom he has complete confidence. As test data can have major economic consequences and as the foundryman usually cannot check the quality of the testing procedures confidence in the organization is a prerequisite.

The next step is consultation with the appropriate control authorities. The foundryman along with the testing organization must involve themselves in this because regulations are sometimes not easily understood, and frequently interpretation is modified by political and community attitudes. Authorities will be aware of changes in enforcement policies, or pending changes in legislation, and the foundryman cannot expect outside testing organizations to be cognizant of these considerations.

The number and type of tests to be taken must be agreed on in advance by all parties concerned. Frequently, meeting the specifications of the pertinent code dictate the number and kind of samples to be run. At other times the purchase agreement between vendor and foundryman specifies testing methods. If discretion can be used the use of several short tests is recommended over one longer one. When several results can be compared, any large differences are evident. If these differences are not as a result of operational changes or adjustments they may indicate error in the test procedure or malfunction of the test equipment. One test of long duration gives only one answer with no basis for comparison. Accuracy and precision of testing is controlled as much by the care exercised and quality of the testing personnel as it is by the test procedure.

Errors in each manipulation such as weighing, measuring gas volume, and calculating results must not exceed 1 percent and should be kept under that if possible. In this way cumulative errors can be held to little more than 1 percent.

CUPOLA OPERATING AND TEST CONDITIONS

Due to the various possible modes of operation of cupolas and cupola systems, it is recommended that cupola emissions be evaluated under conditions that characterize normal or average cupola operations at any particular plant.

Particulate matter emitted via raw cupola stack gases consists principally of iron oxides and silica from the charge metal and impurities adhering to the charge metal plus combustible matter. Secondary combustion in the upper portion of a cupola stack will tend to reduce the combustible portion of the particulate emissions to ash if temperature and retention time are sufficient.

Cupola stack gas will also contain some vapor from substances which reaches the melting zone and is volatilized. These substances include silicon, zinc and silica (sand). The degree of volatilization will depend on melting zone temperature which is influenced by changes in the fuel (coke and/or gas) ratio, preheating of the blast air or scrap and enrichment of the blast air with oxygen. Consequently, it is of utmost importance that the factors affecting melt zone temperature be normal before testing begins. Equally as important, materials that can cause fuming, such as galvanized iron, sand, and silicon, for example, be added in normal amounts during the test period. Changes from normal melt process can result in emissions which are markedly better or worse than will be obtained during everyday operation. Either result will be unsatisfactory.

The particulate matter emanating from a cupola has a wide range of particle size distribution which influences the correct choice of stack testing method. For many cupolas, peaks in particle sizes can be found on distribution curves at three ranges. These are in the 200 to 500 micron range, the 20 to 50 micron range and the 5 micron and below range.

Many factors influence the particulate emission rates of a cupola system. These include the rate of cupola operation, the character, cleanliness and method of introduction of the charge material, the type, size and amount of the coke used, the frequency, length of time and number of periods when tuyere blast air is operative or inoperative during any period, the type of metal being melted, the method and type of alloy introduction, and other diverse factors.

It is necessary, therefore, that each cupola and cupola system be individually analyzed to determine conditions under which stack or source emission tests are needed to define the full range and character of its emissions.

One of the factors having a most profound effect in cupola emissions is the rate of cupola melting; as cupola blast air and coke input is increased to accommodate higher melting rates, cupola emissions increase significantly. It is important, therefore, that cupola source-emission tests be conducted at melting rates approaching the normal expected rate of cupola operation if the results are expected to characterize emissions for the system. Often times it is not practical to operate at maximum melting rates since melting rates must reflect current production and pouring schedules. It should be appreciated, however, that cupola charging and melting rates have a profound influence on cupola emissions.

If for any reason tests during either start-up or burn down periods are made such tests should be kept and evaluated separately from each other as well as all others.

If various metals are produced at various times from the same cupola (such as gray and cutile iron) it is desirable that the emissions be evaluated for each type produced if there is a difference in melting conditions. The melting conditions that would tend to require evaluation in terms of differences in emissions would be reflected by variations in blast air rates, coke rates and charge metal characteristics.

Prior to any field test period the testing firm should be consulted for recommendations as to the number of days and number of test runs to be conducted to define the full range of cupola emissions consistent with cupola operating practices and other pertinent considerations. It is important that the plant's full range of operations be evaluated consistent with the stated objectives of the emission test program.

OBTAINING MEANINGFUL TEST DATA

For short run jobbing cupolas, it is recommended that a minimum of three dustloading test determinations be conducted of cupola emissions as part of any emission study. A volumetric determination should be conducted for each of the three test periods. To make the emission data be the most meaningful it is necessary and desirable that detailed records be kept of cupola operating conditions concurrent with the emission studies.

The emission test program can usually be conducted in one to three days of field sampling by an experienced testing organization. The following minimum information is considered necessary in establishing and fixing cupola operating conditions. It is necessary that these cupola operating data be secured concurrently with stack emission studies:

1) Nature, weight and constituents of all cupola charges.
2) Number and time of all cupola charges made on the test date(s).

3) Cupola blast air record showing volume changes during test. Verify that records indicate volume introduced but not quantities diverted as a means of throttling.

4) Presence of, type, number, capacity and location of afterburners.

5) Existence of gas ignition in the stack.

Ample precedents exist for evaluating the emission performance of only one cupola in a bank of two cupolas that are operated on alternate days. This situation is particularly valid if both cupolas are of the same size, oerate from the same tuyere blast air supply, are used in the production of similar types of iron and are operated at the same approximate rates.

If there are marked variations or changes in the operation of a 2-bank cupola system, particularly with respect to the factors outlined above, it is recommended that each cupola be evaluated individually for its emission potential. The design of a single emission control system serving a dual bank of cupolas must be predicated on achieving conformance with regulations for the most severe conditions of cupola operation during the normal production part of the melt cycle. For the larger job-shop cupola-operators and for the production foundry it is recommended that a minimum of two days field testing of cupola emissions be conducted. This type of test program will permit the operation and evaluation of both cupolas in a two unit bank.

The cupolas themselves should be operated at normal melting rates during the test period. Test dates should be selected when foundry pouring schedules will permit normal operation.

It is not necessary to obtain a gas analysis to determine gas density from the cupola because the difference in weight between air and the combustion gases is insignificant for exhaust volume calculation purposes.

SAMPLING PROCEDURES AND EQUIPMENT

A major problem in sampling and analysis is that high accuracy and precision must be obtained in a working foundry, where conditions are not conducive to laboratory-type manipulations. To achieve effective installation and operation of a sampling train in a foundry requires someone who is not overly worried with minute detail. On the other hand, when the critical analytical measurements and manipulations are made, the greatest attention to cleanliness, accuracy, and detail is required.

The sampling equipment required for this work must fit the same pattern. It must be simple, rugged, and yet capable of high accuracy. In general, it must be highly portable. Reliable equipment is available from several vendors, and all qualified testing groups have their own.

a. Filtering Media

A good filtering medium is a prerequisite to accurate sampling. Efficiency of collection must be at least 99 percent for all particulates encountered. An ideal filter medium should be very light so that accurate weight differences can be obtained from small samples. The filter should also be strong and resistant to both heat and moisture.

No medium available has all these properties so a compromise must be made. Readily available media and some of their characteristics are listed below. Reliable suppliers will give the characteristics of their products on demand.

FILTER PAPER

Conventional filter paper, made from cellulose, comes in hundreds of grades; most of them are not suited to fine particulate filtration, but some are specially designed for this service. They have good mechanical strength, good resistance to moisture, and reasonable heat resistance. Conventional paper must be dried and desiccated before each weighing, and must weighed on a balance from which moisture can be excluded. Ideally the paper should be allowed to reach equilibrium in a constant-humidity room, and should be weighed there.

GLASS FIBER FILTER PAPER

Glass fiber filter paper will withstand higher temperature than conventional paper, but it should be remembered that a plastic binder is used in the manufacture of most of this paper and that the binder lowers temperature resistance. Some paper is made without binder and this is much more resistant to temperature. However, this material lacks mechanical strength, and the unbonded variety is particularly weak. Glass fiber filter paper has the great advantage that it is not sensitive to humidity and so can be used where a dessicator is not available.

THIMBLES

The Soxhlet thimble has been used widely in the past. The thimbles are made of two materials, paper and ceramics. The paper thimbles have the same strengths and weaknesses as ordinary paper, and the same precautions apply. The ceramic ones come in a variety of porosities. If the pores are small enough for this work, rates of filtration will be extremely small. In addition, ceramic thimbles are very heavy so that large samples must be weighed to obtain accuracy. Thimbles of any type are not recommended for this work.

A variety of cloth materials are used for filtering particulates. Usually efficient filtration results only after a coating of particulate has been built upon the cloth. This buildup occurs most rapidly when the sampled gases contain large amounts of particulate, hence sampling error is minimized.

When particulate loading is low, such as when sampling cleaned gas, significant error can be introduced unless the fabric is 99 percent efficient on the first material that deposits.

b. Weighing

The first steps in sampling is weighing the filter paper, or other medium. Each paper should be marked with a number before weighing. The common practice of writing the weight on the paper after it has been obtained creates an error equal to the weight of the ink used. Much larger errors can result from the handling required to write on the paper. Lastly, and most importantly, the practice is poor technique, and, if allowed, will encourage other slovenly practices. The atmosphere in an ordinary analytical balance can be dried to some extent if a small beaker of concentrated sulfuric acid or container of silica gel is placed inside and the doors are kept closed.

If filter papers are weighed on one balance initially, and on a second when loaded, the second balance should be checked for consistency with the first. This can best be done by checking the weight of pre-weighed paper, and applying a correction if required. Accuracy on the total weight is not vital, but the difference between initial and final weights, which represents the weight of the sample, is critical.

c. Flow Measuring

Volume flow rate measuring devices must be preceded by system components to minimize the surging or pulsating effects normal in cupola operation and sampling. The use of flow rate measuring devices in testing effluents from a dynamic system, such as a cupola, requires that frequent readings be taken (2 or 3 minutes reading cycle should be the maximum time period between readings) and that all readings must be conducted on a stopwatch timed basis.

It is recommended that sampling volume flow rate measurements be taken using two different flow measuring mechanisms in any high volume sampling train. The average of the two sampling volume rate measurements and computed sampling volumes should then be used in the subsequent dustloading calculations.

d. Flushing the Sampling Train

At the end of each dustloading test run it is imperative that the sampling train (nozzle, connecting tube or hose and sampler) be thoroughly cleaned and flushed. Distilled water should be used and introduced into the nozzle at high velocities to aid in scrubbing the sampling train.

The particulates flushed from the sampling train should be handled, weighed and separately determined. Significant quantities of particulates are deposited in any sampling train, so it is important that this material be included with the sampled catch when computing the dustloading test results.

e. Velocity-Volumetric Tests

An S-type pitot tube is preferred to a regular pitot tube because it is not as prone to plugging. Stainless steel, Iconel or other high temperature resistant material should be used in the pitot tube construction. A ruggedly constructed inclined draft gage is recommended for use in the velocity and dustloading tests. The pitot tube should be checked and calibrated according to the manufacturers recommendations at regular intervals to establish the proper correction factor to be used in the volumetric calculations.

f. Sampling Trains and Sampling Equipment

Few emission sources offer the trying field test conditions attendant to sampling as do cupola systems. The need also cannot be emphasized enough for rugged field sampling equipment for this testing. A schematic diagram of sampling apparatus for the static balanced tube method of sampling, incorporating recommendations for cupola effluent source emission sampling is presented in Fig. 1.

A possible commercial source for various components of the sampling train is indicated in Table 2. This is not to be construed as an endorsement of any particular manufacturer but is illustrative only of the rugged type of test equipment recommended for cupola source sampling.

When assembling sampling equipment, joint sealing materials should not be exposed to the sampled gas stream where adherence of the particulate could occur. Long-radius bends should be used instead of elbows to facilitate cleaning. The probe should be just long enough for the task at hand. The rest of the train should be assembled and tested for leaks. If the meter is a dry gas meter, it is to be calibrated before each use. If an orifice meter, or flow-meter type, is used it must also be calibrated each time, and it must, in addition, have enough sensitivity so that readings can be read to less than 1 percent. Finally, if volume is obtained by multiplying an instantaneous reading by the time of operation, fluctuations must be kept to 1 percent.

The vacuum pump or compound air ejector must be the last element of the sampling train unless it can be proved that there is no leakage through the packing, etc., under the worst conditions that can be visualized.

g. Analysis of Captured Particulate

It is recommended that the procedure for weighing and determining size distribution of the captured particulate be used as stated in the ASME PTC 27-1957 Section 4 Paragraphs 75-79 (see Appendix).

Fine particulate matter should be sized and analyzed within 24 hours after the sample is taken to minimize agglomeration and a possible change in character. It is most desirable if the sample is dried immediately after the test has been run to prevent degradation.

The minus 44 micron fraction of the collected particulate must be carefully handled and analyzed because of the strong tendency to agglomerate.

SECTION I - SAMPLING RAW PARTICULATE EMISSIONS IN THE CUPOLA STACK

Recommended Test Method and Procedures

A thorough and complete review of the available test methods and procedures used in the conduct of source emission studies has resulted in the recommendation of the following basic requirements as essential to an acceptable evaluation of the test methods:

1) In order to obtain a truly representative sample of coarse particulates from the gas stream a large volume sampling train should be used. The sampling nozzle should be constructed of stainless steel having a minimum inside diameter of 3/4 inches, since raw cupola emissions cover a broad range of particle sizes, with individual particles not uncommonly ranging up to 3/8 inch diameter or larger.

2) Particulate matter is defined consistent with the definition accepted by the dust collection industry and as adopted in the American Society of Mechanical Engineers Performance Test Code 21-1941, Dust Separating Apparatus and Performance Test Code 27-1957, Determining the Dust Concentration in a Gas Stream. See item 1 in the Appendix. In essence, this defines particulate matter as all filterable solids present at standard temperature in an effluent gas stream.

3) It is necessary that a truly "isokinetic" sample of gases and solids be secured by the sampling system. This requirement is a practical consideration dictated by the wide range of

particle sizes involved and, therefore, the special need for securing a truly isokinetic sample of the effluent solids.

4) When sampling in the cupola stack, water-cooled corrosion-resistant, sampling probes and sampling nozzles are required. This is a practical requirement since cupola temperatures in excess of 1200°F are common, and sample contamination by corrosion products formed in the nozzles and probes of the sampling system must be prevented. Water-cooling also serves to preserve the sampling probes from deterioration and distortion.

5) The American Society of Mechanical Engineers Performance Test Code 27-1957, Determining Dust Concentration in a Gas Stream, with modifications as outlined below offers the best and most practical test method and test procedures for the conduct of source emission studies from cupolas. The following are additional important considerations in the sampling of cupolas and cupola systems when utilizing as a broad base the test procedures and techniques embodied in ASME PTC 27-1957, Determining Dust Concentration in a Gas Stream. See item 2 in the Appendix. The criteria supplement the methods and procedures contained in ASME PTC 27, when applied to cupola source emission testing:

a. Test Location and Test Openings

A test location in a cupola stack must at best be a compromise. The location should be as far above the top of the charge door opening as practical but be at least one equivalent cupola inside daimeter below the top of the cupola stack. This location will require that protective shelter be provided since test personnel and equipment may be subjected to possible fallout of particles.

Test ports should consist of two six inch pipe nipples (schedule 40) installed radially in the cupola shell and cupola lining at 90 degrees to each other. Both 90 degree test ports must be accessible from the sheltered test platform. Six-in test ports are usually required to accommodate high volume sampling nozzles. An acceptable test platform can usually be constructed using temporary steel scaffolding. Corrugated metal sheeting can be used for the roof of the test platform. The six-inch pipe nipple test ports should protrude out a few inches from the cupola shell and should be flush with the inside of the cupola lining. The test port nipples should be fillet-welded to the cupola shell. The threads of the pipe nipples should be graphited and six-inch pipe caps installed hand tight so that they can be readily removed during the test period.

b. Method of Subdividing Cupola Stack

The cupola stack cross-sectional area should be measured at the test elevation. Due to refractory erosion and/or the buildup of slagged deposits which affect the cupola cross section, it is important that the cupola cross section and cross sectional area be determined at the test elevation. The ASME PTC 27 test code prescribed procedure (see item 2 in Appendix) should be followed in determining the location of the test points to be used in both the volumetric or pitot tube traverses and during the test runs.

A minimum of 12 points should be used as sampling locations in traversing a cupola stack in the dustloading test runs. Additional sampling points should be used when the maximum to minimum velocity variation in the velocity profile approaches, or exceeds, a 2 to 1 figure.

It is important that dust sampling be conducted at each test point and that the dustloading test-data sheet reflects the sampling conditions at each test point in traverse of the cupola from each test port. The practice of using a much smaller number of test points during the dustloading test runs, as compared to a large number of points used in the velocity checks, is almost certain to bias the test results and cause the results to be of a questionable nature with respect to securing a representative cupola sample.

c. Number and Duration of Test Runs

Test runs shall consist of a minimum of 60 minutes actual dust sampling. Based upon a minimum of 12 points of dust sampling of the cupola cross section from the two 90 degree test ports, an acceptable minimum sampling schedule would consist of sampling for 5 minutes at each of the 12 points. The field test data sheets and the test report must clearly reflect the location and the time of sampling at each of the sampling points used. A minimum of three sets of flow, temperature and pressure readings should be taken at each sampling point. The field data shall be logged and should reflect the dynamic conditions of cupola flows and sampling rates at each test point.

Readings of sampling flow rates, temperatures, pressures, gas analyses and other pertinent test data which are part of each dustloading test run should be taken on a 2 (maximum 3) minute cycle at each sampling point during each dustloading test run. The total sampling program should be conducted under stopwatch timing precision.

Three dustloading test runs and 3 velocity-volumetric test runs should be conducted in a single day of field sampling, as previously mentioned.

d. Sampling Probes

Sampling probes used in the dustloading test runs of raw gas should be of water-cooled, stainless steel construction. The sampling probes should be a minimum of 3/4 inch inside diameter, and preferably of larger inside diameter for tests conducted on raw gas emissions. Conventional smaller diameter test probes are suitable for use on the downstream side of dust collectors, but should not be used in raw gas sampling.

Either a standard or null type probe may be used for sampling raw cupola gases. Whichever probe is employed, a truly isokinetic sample must be taken at all test points during all test runs.

A null sampling probe of either the balanced static pressure type or balanced impact pressure type can be used. Null type probes are prone to introduce minimum error as their diameters increase and as the velocity of the flow system increases.

A null sampling probe must be calibrated and of such a size as to give the minimum sampling error (deviation from isokinetic) for the expected sampling velocity range.

Either type probe presents certain shortcomings which must be compensated for under the adverse, dynamic and widely varying flow conditions attendant to normal cupola operation.

Cupola velocities can be expected to range from 600 to 2400 ft/min. depending upon the size of the cupola and the rate of cupola operation. Normal operating velocity ranges can be expected to be 1000 to 1800 ft/min.

Fixed rate sampling trains, based upon an occasional velocity determination made at some fixed time, are unacceptable for cupola source sampling since such methods completely ignore the dynamic nature of the cupola melting process.

e. Filter Media

Due to the need for a large diameter sample probe and the necessity of isokinetically sampling the gas stream, a high volume sampling train is mandatory. The filtering media used for removing particulate from the gas stream must be of sufficient size to maintain the sampling rates necessary without imposing undue pressure drop restrictions on the sampling train.

The advantages and disadvantages of some of the various filtering media that can be used in removing the particulates from the sampled gas stream are stated in ASME PTC 27 Section 4 Paragraph 59 (See Appendix).

FOOTNOTE: Cloth is often used as the filtering media because of its high collection efficiency, good flow permeability, ability to be shaped or adapted to any sampler configuration, and freedom from plugging or excessive pressure buildup under minimum condensation conditions.

In the event that a cotton sateen fabric is selected it must be thoroughly washed and rinsed prior to use to be free of starch and sizing materials. This filter medium has as its most serious limitation a humidity or moisture pickup tendency. This problem can be adequately dealt with by proper and skilled weighing and handling techniques using an enclosed single pan desiccated analytical balance.

Sampler units housing the filter medium should be made or lined with corrosion resistant material and must permit ready and free insertion and removal of the filter medium. Sampler units must consist of airtight enclosures to ensure that all sampled gases pass through the filter medium, be capable of easy field cleaning and of conserving the sampled dusts with a minimum of sample loss in filter handling.

To facilitate transfer of collected material and prevent the possibility of incandescent particles from contacting the final filter medium it may be desirable to incorporate a small stainless steel cyclonic collector ahead of the ultimate filter medium. Such cyclones tend to remove the larger particulates and prolong the sampling period before the pressure buildup on the filter medium restricts isokinetic sampling, due to reduced sampling flow rate capability.

Such cyclones offer the additional advantage of providing a convenient method of measuring the gas sampling flow rate. This can be accomplished by calibrating the pressure drop across the cyclone collector unit entailing the measurement of the pressure differential across the cyclone, the temperature and the static pressure at that location.

FOOTNOTE: Scrubber (impinger) or condensing systems are considered unsatisfactory for particulate filtration in cupola sampling trains. Such systems promote and cause the formation of reaction products which were not present in the cupola gas stream. Since most available impinger or wet collecting apparatus, are associated with low volume sampling rates (not to exceed 1.0 cfm), it can be seen that they do not lend themselves well to high volume rate sampling without the use of multiple, parallel units.

While it may be of interest in some instances to determine if condensible material is present in cupola effluents such determinations are beyond the scope of this recommended practice for particulate.

When a gas analysis is desired it is recommended that a continuous carbon dioxide and/or a continuous oxygen analyzer be used to measure these gas constituents. Periodic checks can also be made using an Orsat gas analyzer to verify the performance of the continuous gas analyzer or to check on the total gas composition (CO_2, O_2, CO, N_2). The continuous gas analyzer should be read on a two or three minute cycle throughout each test run and the time noted. Results of each Orsat gas analysis conducted should be clearly indicated on the field data sheets and in the test report.

Sulfur oxide emissions from cupola systems are of such a low order that it is usually unnecessary to measure them in light of present day standards.

---

f. Sampling Volume Flow Rate

The need for a high volume sampling system to secure representative samples from cupola raw gas effluents often mitigates against the use of an integrating gas meter for measuring the sample gas volume although such are available to handle the flow ranges covered by 3/4 to 2 inch inside diameter dust sampling nozzles. However, portability requirements for such meters leave much to be desired and adverse field conditions in cupola sampling often preclude the use of such meters.

Sampling volume flow rate measurements can be made by flowrator systems, calibrated pressure drop mechanisms such as orifices, venturis or other similar flow measuring devices.

SECTION II - RAW GAS TEST LOCATION IN DUCT AHEAD OF COLLECTOR

Tests are often conducted to determine performance of collectors installed for cupola gas cleaning. Often a sample location in the connecting duct will have advantages over that of a cupola stack location because -

1. Gases will be cooled, usually by evaporation of water, to temperatures below 500°F.
2. Location more accessible.
3. Dustloadings and gas velocity more uniform thru cross section of sampling area.

   (Duct velocities usually in teh 3000 - 5000 fpm range.)

   In such locations:

   a. Number of sample points can correspond to ASME PTC 27 and need not be the minimum of 12 recommended for the cupola stack.
   b. Gas volume will include substantial proportion of water vapor and influence gas density.
   c. Some dust, especially of the coarser fractions, can bypass the sample area if there is substantial run-off of cooling water or for dust fallout in cooling towers, external combustion chambers, etc.

Whenever possible, catch from collector should be obtained and checked against calculated collected quantity from inlet and outlet samples. It is often difficult to get a sample covering only the test period, but often feasible to obtain quantity collected during a complete melting cycle. In the latter case, daily average data can be compared to short test runs of the sampling equipment.

Comparison of coarse fraction in the catch with the quantities reported by sampling will also give an indication of effectiveness of the sampling technique of such fractions. When indicated, catch from the collector needs to be augmented by inclusion of fallout in preceding system elements as noted in Item c.

SECTION III - SAMPLING CLEANED CUPOLA GASES

General

Sampling behind a gas cleaner alleviates some of the problems experienced when sampling raw cupola gases. Extremely large particles are no longer present permitting the use of conventional 1/4" or 3/8" diameter sampling probes and lower sampling volumes. The violent velocity fluctuations experienced in a cupola stack have been moderated; and the high temperatures of raw cupola gases have been reduced. On the other hand, a different problem is accentuated. Gas cleaning equipment is expensive, and is usually sold to meet a specified emission standard. Since performance curves for emissions become asymptotic, small changes in performance can cause large expenditures in equipment alteration, therefore accuracy of testing becomes more critical.

Because the gas sampled is hot and humid, the probe or filter holder must be heated to stop condensation on the walls of the apparatus from occuring. Such condensate will interfere with the filtration of particulate.

Cupola off-gases are almost always cooled by direct contact with water, so it can be a-sumed that they are humid after they have passed through a cleaning device, whether a wet scrubber or not. Consequently, a condenser must be inserted in the filtering train. This serves two purposes. First, it removes excess water which may condense and damage the gas meter. Secondly, and of vital importance, a condenser gives assurance that the gas passing through the train is saturated at an identifiable point. This provides the basis for exact calculation of the volume of dry gas metered, converted to standard conditions.

An acceptable procedure for testing is "Determining Dust Concentration in a Gas Stream", PTC 27-1957, published by the American Society of Mechanical Engineers.

While isokinetic sampling is not as critical for cleaned gases because of the small particle sizes involved, its use is recommended, following the same procedure of test locations, sample time, pitot traverse and data log recommended in Section I and II.

FIGURE 1

SCHEMATIC DIAGRAM OF SAMPLING APPARATUS

STATIC BALANCED TUBE METHOD OF SAMPLING

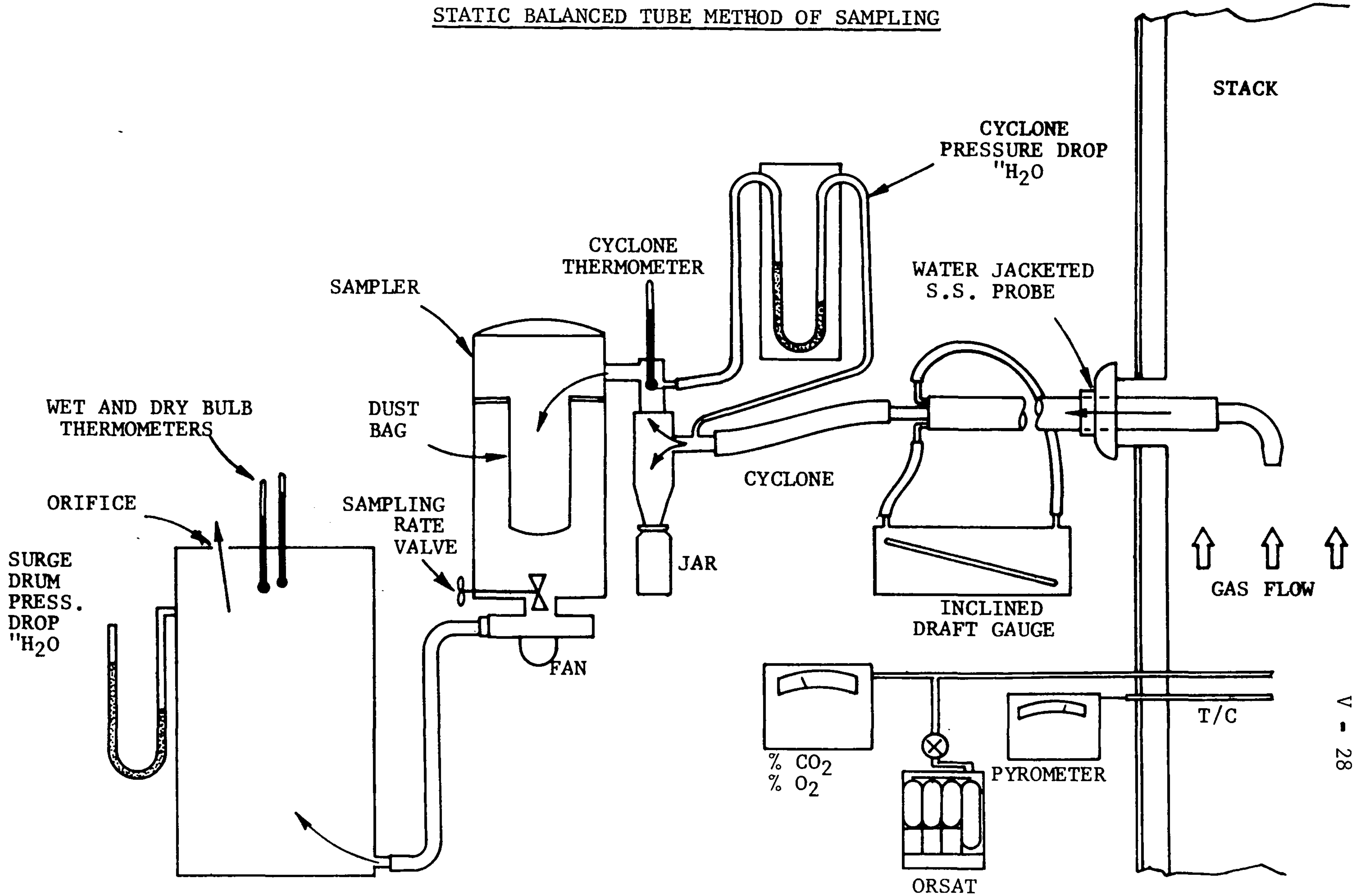


TABLE 2 - REPRESENTATIVE SOURCES OF COMMERCIALLY MANUFACTURED COMPONENTS

	Component	Source
1.	Stainless steel, water-cooled static balanced, tube sampling nozzle-3/4 in. minimum ID.	Individually designed and constructed to meet nozzle diameter and probe length needs. Fitted with 6 in. pipe cap and pipe sleeve. Nozzles are to be calibrated to effect isokinetic sampling with minimum sampling error at the optimum velocity range for each different probe diameter. An acceptable nozzlehead design is schematically illustrated in ASME PTC 27 (Fig. 2).
2.	Inclined draft gage and holder, pitot tube.	Industrial Engineering Instrument Co., Allentown, Pennsylvania
3.	Stainless steel cyclone	UOP Air Corrections Division Darien, Connecticut
4.	Sampler	Fabricate to meet filter media confinement and handling requirements.
5.	Manometer	The Meriam Instrument Co., Cleveland, Ohio
6.	Thermometer	Weston Electrical Instrument Corp., Newark, New Jersey
7.	Industrial exhauster	Clements Manufacturing Co., Chicago, Illinois
8.	Continuous gas analyzer	Thermco Instrument Corp., LaPorte, Indiana
9.	Orsat gas analyzer	Hayes Corp., Michigan City, Indiana
10.	Pyrometer and thermocouple	Alnor Instrument Co., Division Ill. Testing Laboratories, Inc. Chicago, Illinois

VI - GLOSSARY OF TERMS

ACFM - Actual cubic feet per minute; refers to the volume of gas at the prevailing temperature and pressure.

Acid Lining - A refractory furnace lining essentially of silica.

Additive - A substance added to another in relatively small amounts to impart or improve desirable qualities, or suppress undesirable qualities. As additives to molding sand, for example, cereal, sea coal, etc.

Aerosol - Small particles, liquid or solid, suspended in the air. The diameters vary from 100 microns down to 0.01 microns or less; for example, dust, fog, smoke.

Afterburner - A device for burning combustible materials that were not oxidized in an initial burning process.

Agglomeration - Gathering together of small particles into larger particles.

Air Cleaner - A device designed for the purpose of removing atmospheric airborne impurities such as dusts, gases, vapors, fumes and smokes.

Air Filter - Any method used to remove gases and particulates from the environment and stack emission; it may be of cloth, fibers, liquid spray, electrostatic, etc.

Air Furnace - A reverberatory-type furnace in which metal is melted by heat from fuel burning at one end of the hearth, passing over the bath toward the stack at the other end.

Air Pollution - The presence in the outdoor atmosphere of one or more air contaminants or combinations thereof in such quantities and of such duration that they are or may tend to be injurious to human, plant or animal life, or property, or that interfere with the comfortable enjoyment of life or property or the conduct of business.

Anneal - A heat treatment which usually involves a slow cooling for the purpose of altering mechanical or physical properties of the metal, particularly to reduce hardness.

Baghouse - A large chamber for holding bags used in the filtration of gases from a furnace to recover metal oxides and other solids suspended in the gases. It's a form of dust collector and the bags may be constructed of natural, synthetic, or glass fibers.

Baked Core - A core which has been heated through sufficient time and temperature to produce the desired physical properties attainable from its oxidizing or thermal setting binders.

Balanced Blast - Arrangement of tuyeres in a cupola which provides for distributing or balancing the blast as required between upper and lower levels of the melting zone.

Basic Lining - In a melting furnace, the inner lining and bottom composed of materials that have a basic reaction in the melting process, usually either crushed burned dolomite, magnesite, magnesite bricks or basic slag.

Bed - Initial charge of fuel in a cupola upon which the melting is started.

Blast - Air driven into the cupola furnace for combustion of fuel.

Blast Volume - The volume of air introduced into the cupola for the burning of fuel. This volume governs the melting rate of the cupola and approximately 30,000 cubic feet of air is required per ton of metal melted.

Briquette - Compact cylindrical or other shaped block formed of finely divided materials by incorporation of a binder, by pressure, or both. Materials may be ferroalloys, metal borings or chips, silicon carbide, coke breeze, etc.

Burden - A collective term of the component parts of the metal charge for a cupola melt.

Burned Sand - Sand in which the binder or bond has been removed or impaired by contact with molten metal.

Canopy Hood - A metal hood over a furnace for collecting gases being exhausted into the atmosphere surrounding the furnace.

Cantilever Hood - A counterbalanced hood over a furnace that can be folded out of the way for charging and pouring the furnace.

Cast Iron - Essentially an alloy of iron, carbon and silicon in which the carbon is present in excess of the amount which can be retained in solid solution in austenite at the eutectic temperature.

Catalytic Combustion - A device for burning combustible gases, vapors, aerosols and odorous substances, reducing them to water vapor and carbon dioxide.

Centrifuging - A method of casting, employing a core and depending on centrifugal force to make the metal more dense and strong in the outer portion of the casting. The mold cavities are usually spaced symmetrically about a central sprue, and the whole assembly is rotated about that axis during pouring and solidification.

Cereal Binder - A binder used in core mixtures and molding sands, derived principally from corn flour.

Charge - The total ore, ingot, metal, pig iron, scrap, limestone, etc. introduced into a melting furnace for the production of a single heat.

Charging Door - An opening in the cupola or furnace through which the charges are introduced.

Coke - A porous gray infusible product resulting from the dry distillation of bituminous coal, which is used as a fuel in cupola melting.

Coke Breeze - These are fines from coke screenings.

Convection - The motion resulting in a fluid from the differences in density and the action of gravity due to temperature differences in one part of the fluid and another. The motion of the fluid results in a transfer of heat from one part to the other.

Cope - The upper or topmost section of a flask, mold, or pattern.

Core - A separate part of the mold which forms cavities and openings in castings which are not possible with a pattern alone. Cores are usually made of a different sand from that used in the mold and are generally baked or set by a combination of resins.

Core Binder -	Any material used to hold the grains of core sand together.
Core Blower -	A machine for making cores by blowing sand into the core box by means of compressed air.
Core Oven -	Specially heated chambers for the drying of cores at low temperatures.
Core Sand -	Sand for making cores to which a binding material has been added to obtain good cohesion and porosity after drying.
Crucible -	A vessel or pot made of a refractory such as graphite or silicon carbide with a high melting point and used for melting metals.
Cupola -	A cylindrical straight shaft furnace usually lined with refractories, for melting metal in direct contact with coke by forcing air under pressure through openings near its base.
Cupola, Hot Blast -	A cupola supplied with a preheated air blast.
Cupola Stack -	The overall top column of the cupola from the charging floor to the spark arrestor.
Cyclone - (centrifugal collector)	A device with a control descending vortex created to spiral objectionable gases and dusts to the bottom of a collector cone for the purpose of collecting particulate matter from process gases.
Cyclonic Scrubber -	Radial liquid (usually water) sprays introduced into cyclones to facilitate collection of particulates.
Density -	Ratio of the weight of gas to the volume, normally expressed as pounds per cubic foot.
Desulfurizing -	The removal of sulfur from molten metal by the addition of suitable compounds.
Direct Arc Furnace -	An electric arc furnace in which the metal being melted is one of the poles.
Drag -	The lower or bottom section of the mold, flask or pattern.

Ductile Iron - Iron of a normally gray cast type that has been suitably treated with a nodularizing agent so that all or the major portion of its graphitic carbon has a nodular or spherulitic form as cast.

Duplexing - A method of producing molten metal of desired analysis. The metal being melted in one furnace and refined in a second.

Dust - Small solid particles created by the breaking up of larger particles by processes such as crushing, grinding, drilling, explosion, etc.

Dust Collector - An air cleaning device to remove heavy particulate loadings from exhaust systems before discharge to outdoors.

Dust Loading - The concentration of dust in the gas entering or leaving the collector, usually expressed as pounds of particulate per 1,000 pounds of dry gas or grains per standard cubic foot.

Efficiency - With regard to dust collectors, it is the ratio of the weight of dust trapped in the collector to the weight of dust entering the collector. This is expressed as a percent.

Effluent - The discharge entering the atmosphere from the process.

Electrostatic Precipitator- A dust collector utilizing a high voltage electrostatic field formed by negative and positive electrodes; the positive, uncharged electrode attracts and collects the gas-borne particles.

Elutriation - The sizing or classifying of particulate matter by suspension in a fluid (liquid or gas), the larger particulates tending to separate by sinking.

Emission - The total pollutants emitted into the atmosphere usually expressed as weight per unit of time such as pounds per hour.

Endothermic Reaction - Designating, or pertaining to a reaction which occurs with the absorption of heat from the surroundings.

Equivalent Opacity - The determination of smoke density by comparing the apparent density of smoke as it issues from a stack with a Ringelmann chart. In effect, it is a measure of the light obscurity capacity of the plume.

Exothermic Reaction -	Chemical reactions involving the liberation of heat; such as burning of fuel and deoxidizing of iron with aluminum.
Fabric Filter -	A dust collector using filters made of synthetic, natural or glass fibers within a baghouse for removing solid particulate matter from the air or gas stream.
Facing Sand -	Specially prepared molding sand mixture used in the mold adjacent to the pattern to produce a smooth casting surface.
Fines -	A term the exact meaning of which varies. 1. Those sand grains that are substantially smaller than the predominating grain size. 2. That portion of sieved material that passes through the mesh.
Flask -	Metal or wood frame without top or without fixed bottom used to retain the sand in which a mold is formed; usually consists of two parts, cope and drag.
Flux -	Material or mixture of materials which causes other compounds with which it comes in contact to fuse at a temperature lower than their normal fusion temperature.
Fly Ash -	A finely divided siliceous material, usually oxides, formed as a product of combustion of coke. A common effluent from the cupola.
Forehearth -	Brick lined reservoir in front of and connected to the cupola or other melting furnaces for receiving and holding the melted metal.
Foundry Effluent -	Waste material in water or air that is discharged from a foundry.
Fourth Hole Ventilation - (Direct Tap)	In air pollution control, using a fourth hole in the roof of an electric furnace to exhaust fumes.
Fume -	A term applied to fine solid particles dispersed in air or gases and formed by condensation, sublimation, or chemical reaction.

Gas -	Formless fluids which tend to occupy entire space uniformly at ordinary temperatures and pressures.
Gate -	The portion of the runner in a mold through which molten metal enters the mold cavity.
Gray Iron -	Cast iron which contains a relatively large percentage of its carbon in the form of graphite and substantially all of the remainder of the carbon in the form of eutectoid carbide.
Green Sand -	A naturally bonded sand or a compounded molding sand mixture which has been tempered with water and additives for use while still in a damp or wet condition.
Griffin System -	A method operating in two stages, to recoup and preheat air by using the latent heat of cupola gases.
Heat Balance -	A determination of the sources of heat input and the subsequent flow of heat usually expressed in equation form so that heat input equals heat output.
Heat Treatment -	A combination of heating and cleaning operations timed and applied to a metal or alloy in the solid state in a manner which will produce desired properties.
Heel -	Metal left in ladle after pouring has been completed. Metal kept in induction furnaces during standby periods.
Holding Furnace -	A furnace for maintaining molten metal, from a larger melting furnace, at the proper casting temperature.
Hood -	Projecting cover above a furnace or other equipment for purpose of collecting smoke, fume or dust.
Hot Blast -	Blast which has been heated prior to entering into the combustion reaction of a cupola.
Indirect Arc Furnace -	An electric arc furnace in which the metal bath is not one of the poles of the arc.
Induction Furnace -	A melting furnace which utilizes the heat generated by electrical induction to melt a metal charge.
Inlet Volume -	The quantity of gas entering the collector from the system it serves (in cubic feet per minute at a specified temperature).

Inoculant -	Material which when added to molten metal modifies the structure changing the physical and mechanical properties of the metal.
Inoculation -	The addition to molten metal substances designed to form nuclei for crystallization.
Ladle Addition -	The addition of alloying elements to the molten metal in the ladle.
Latent Heat -	Thermal energy absorbed or released when a substance changes state; that is, from one solid phase to another, or from solid to liquid or the like.
Lining -	Inside refractory layer of firebrick, clay, sand or other material in a furnace or ladle.
Magnesium Treatment -	The addition of magnesium to molten metal to form nodular iron.
Malleable Iron -	A mixture of iron and carbon, including smaller amounts of silicon, manganese, sulfur and phosphorous, which, after being cast as white iron, is converted structurally by heat treatment into a matrix of ferrite containing nodules of temper carbon, and substantially free of all combined carbon.
Material Balance -	A determination of the material input to the cupola and the output to fully account for all material.
Melting Rate -	The tonnage of metal melted per unit of time, generally tons per hour.
Micron -	A unit of measurement which is 1/25,000 of an inch or a millionth of a meter. Often designated by the Greek letter mu.
Mist -	Visible emission usually formed by a condensation process or vapor-phase reaction, the liquid particles being sufficiently large to fall of their own weight.
Mold -	The form, usually made of sand, which contains the cavity into which molten metal is poured to produce a casting of definite shape and outline.
Muller -	A type of foundry sand mixing machine.

Nodular Cast Iron - (See Ductile Iron)

Opacity - The state of a substance which renders it partially or wholly impervious to rays of light. Opacity as used in an ordinance refers to the obscuration of an observer's view.

Outlet Volume - Quantity of gas exhausting from the collector (in cubic feet per minute at a specified temperature).

Oxidizing Atmosphere - An atmosphere resulting from the combustion of fuels in an atmosphere where excess oxygen is present, and with no unburned fuel lost in the products of combustion.

Oxidation Losses - Reduction in amount of metal or alloy through oxidation. Such losses usually are the largest factor in melting loss.

Particulate Matter - Solid or liquid particles, except water, visible with or without a microscope, that make up the obvious portion of an exhaust gas or smoke.

Parting Compound - A material dusted, brushed or sprayed on patterns or mold halves to prevent adherence of sand and to promote easy separation of cope and drag parting surfaces when cope is lifted from drag.

Pattern - A form made of wood, metal or other materials around which molding material is placed to make a mold for casting metals.

Plume - A visible, elongated, vertical (horizontal when windblown) column of mixed gases and gas-borne particulates emitted from a smoke stack.

Pollutant - Any foreign substance in the air or water in sufficient quantities and of such characteristics and duration as to be injurious to human, plant, or animal life or property, or which unreasonably interferes with the enjoyment of life and property.

Preheater - A device used to preheat the charge before it is charged into the furnace.

Process Weight - The total weight of raw materials, except air, introduced into any specific process, possibly causing discharge into the atmosphere.

Recuperator - Equipment for transferring heat from hot gases for the preheating of incoming fuel or air.

Reducing Atmosphere - An atmosphere resulting from the incomplete combustion of fuels.

Refractory -	Heat resistant material, usually nonmetallic, used for furnace linings, etc.
Reverberatory Furnace -	A large quantity furnace with a vaulted ceiling that reflects flame and heat toward the hearth or the surface of the charge to be melted.
Ringelmann's Scale - (chart)	A system of optical charts reading from all clear to solid black for grading the density of smoke emissions.
Riser -	An opening in the top of a mold which acts as a reservoir for molten metal and connected to the casting to provide additional metal to the casting as it contracts on solidification.
Rotary Furnace -	A furnace using pulverized coal, gas or oil; of cylindrical shape with conical ends, mounted so as to be tipped at either end to facilitate charging, pouring and slagging.
SCFM -	Units standing for Standard Cubic Feet per Minute. The volume of gas measured at standard conditions, one atmosphere of pressure and 70° F.
Sea Coal -	A term applied to finely ground coal which is mixed with foundry sands.
Sensible Heat -	That portion of the heat which changes only the temperature, but does not cause a phase change.
Shakeout -	The operation of removing castings from a sand mold.
Shell Molding -	A process for forming a mold from thermosetting resin bonded sand mixtures brought in contact with preheated metal patterns, resulting in a firm shell with a cavity corresponding to the outline of the pattern.
Shotblasting -	Casting cleaning process employing a metal abrasive propelled by centrifugal force.
Slag -	Nonmetallic covering which forms on the molten metal as a result of the flux action in combining impurities contained in the original charge, some ash from the fuel and silica and clay eroded from the refractory lining.

Smoke - A type of emission resulting from incomplete combustion and consisting predominantly of small gas-borne particles of combustible material present in sufficient quantity to be observable independently of the presence of other solids in the gas stream.

Spark Arrestor - Device over the top of the cupola to prevent the emission of sparks.

Spruc - The channel, usually vertical, connecting the pouring basin with the runner to the mold cavity. In top pour casting the sprue may also act as a riser.

Standard Air - Air with a density of .075 pounds per cubic foot, generally equivalent to dry air at 70° F and one atmosphere of pressure (14.7 psia).

Superheating - Heating of a metal to temperatures above the melting point of the metal to obtain more complete refining or greater fluidity.

Tapping - Removing molten metal from the melting furnace by opening the tap hole and allowing the metal to run into a ladle.

Tuyere - The nozzle openings in the cupola shell and refractory lining through which the air blast is forced.

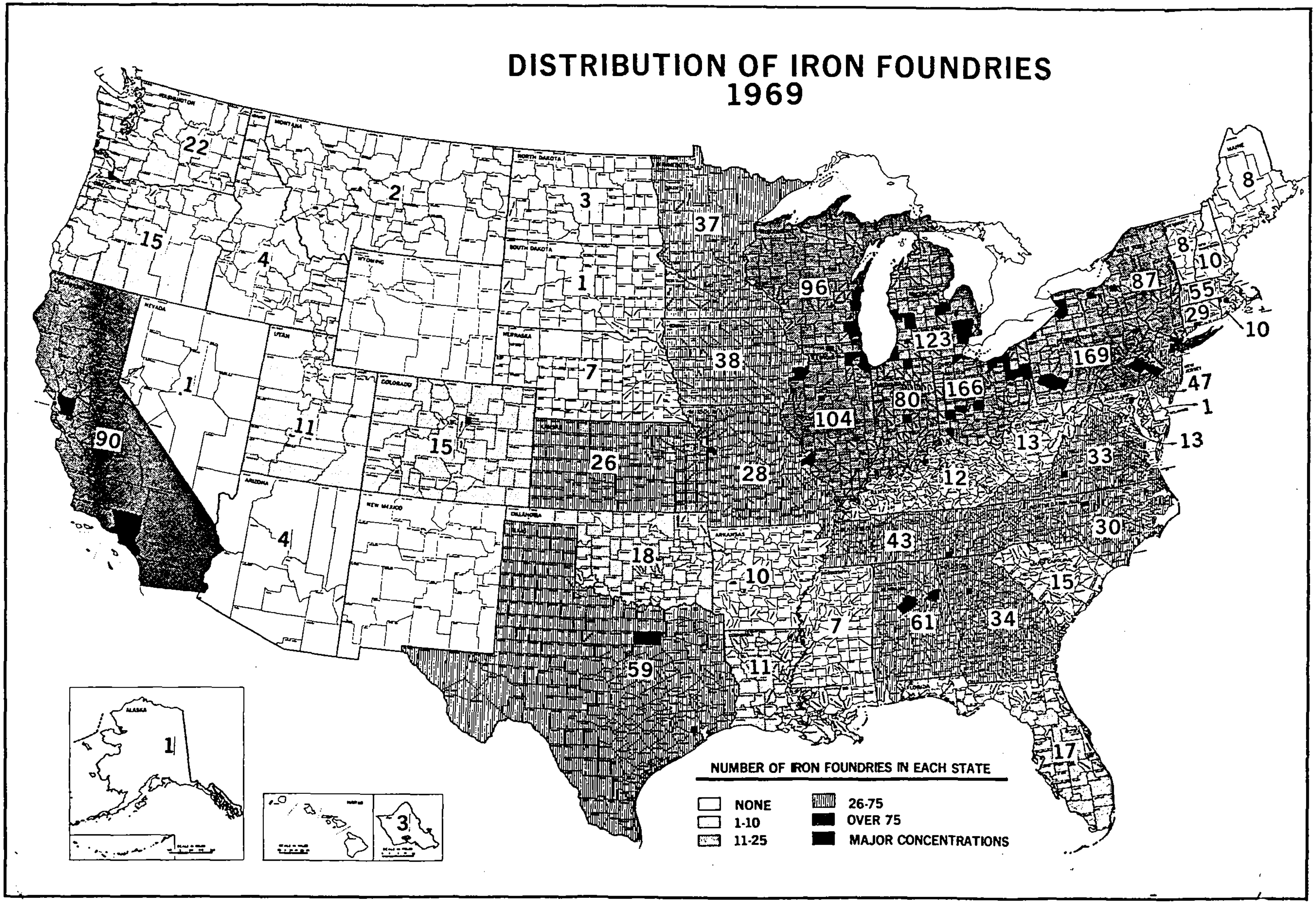
Vapor - The gaseous form of a substance normally in the solid or liquid state and which can be returned to these states either by increasing pressure or decreasing temperature.

Ventilation System - In the foundry, the exhaust ventilation and dust control equipment for the health, safety, comfort and good housekeeping of those who work there.

Venturi Scrubber - In air pollution control, a high velocity gas stream directed into the throat of a venturi of a wet scrubber to separate out particulates.

Wet Cap - A device installed on a cupola stack that collects emissions by forcing them through a curtain of water. The device requires no exhaust fan but depends upon the velocity pressure of the effluent gases.

Wet Scrubber -	In air pollution control, a liquid spray device, usually water, for collecting pollutants in escaping foundry gases.
Wind Box -	The chamber surrounding a cupola through which air is conducted under pressure to the tuyeres.



SOURCE: PENTON PUBLISHING CO.

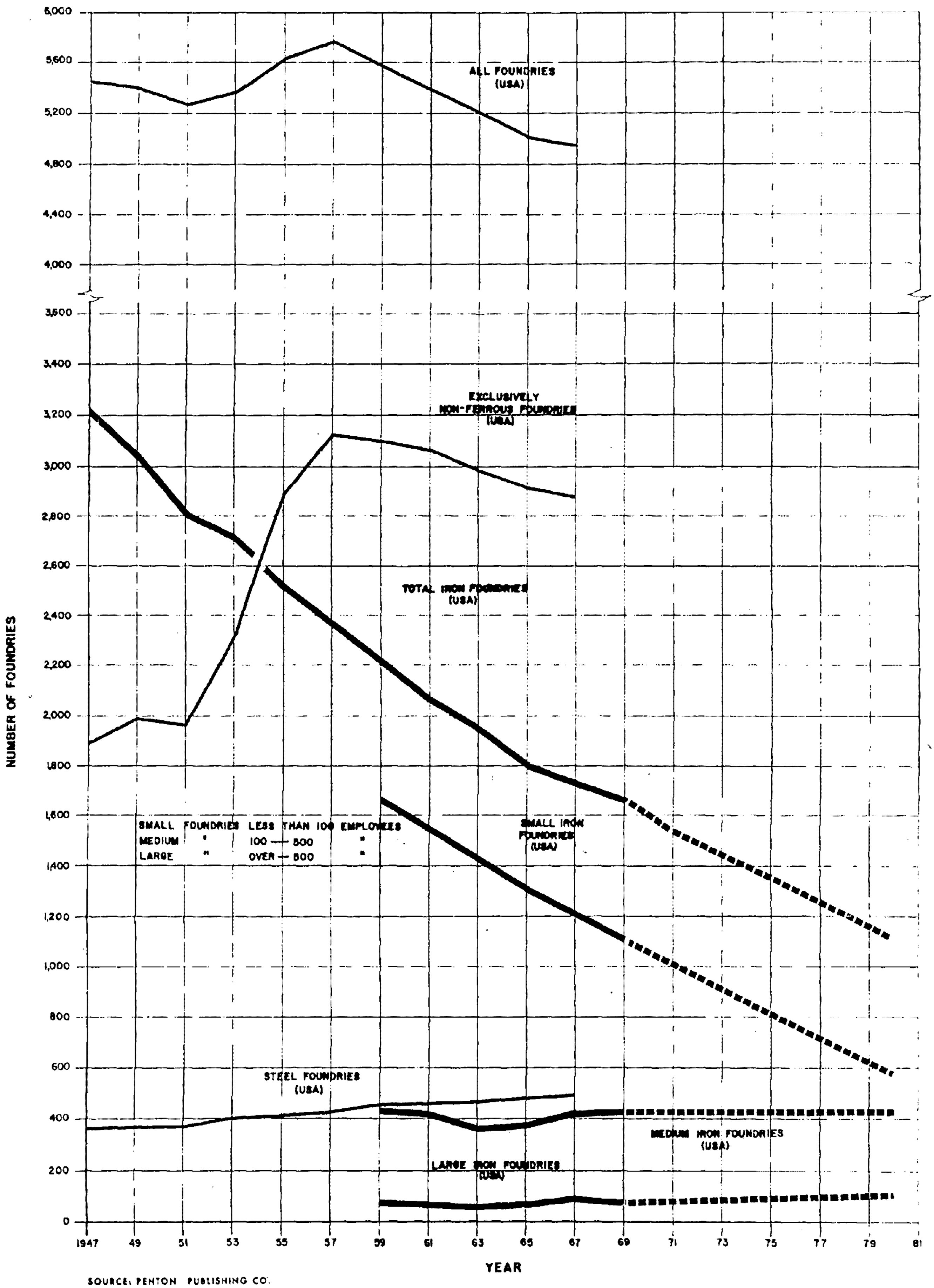
GEOGRAPHICAL DISTRIBUTION OF IRON FOUNDRIES

	Gray Iron				Ductile Iron				Malleable			
	1969	1967	1965	1963	1969	1967	1965	1963	1969	1967	1965	1963
Alabama	56	56	59	65	17	16	17	12	2	3	2	2
Alaska	1	-	-	-	-	-	-	-	-	-	-	-
Arizona	4	3	3	4	1	-	-	-	-	-	-	-
Arkansas	10	11	10	10	1	1	1	1	-	-	-	-
California	88	86	95	102	29	23	24	23	1	1	1	4
Colorado	15	17	18	20	4	3	4	3	-	-	-	1
Connecticut	24	23	24	29	7	6	6	5	4	5	5	5
Delaware	1	2	2	2	-	-	-	-	-	-	-	-
District of Columbia	-	-	1	1	-	-	1	1	-	-	-	-
Florida	17	19	19	20	3	3	2	2	-	-	-	-
Georgia	32	29	32	35	8	6	6	7	-	-	-	-
Hawaii	3	4	3	3	-	-	-	-	-	-	-	-
Idaho	4	4	4	4	1	1	1	1	-	-	-	-
Illinois	97	104	107	113	32	31	29	28	9	10	11	11
Indiana	75	81	75	84	16	12	12	11	4	4	4	5
Iowa	36	37	38	43	8	6	5	5	1	2	1	2
Kansas	24	22	22	23	9	6	7	7	-	-	-	-
Kentucky	11	15	16	16	2	1	-	-	-	-	-	-
Louisiana	10	10	16	13	2	2	2	1	-	-	-	-
Maine	8	8	8	9	1	-	-	-	-	-	-	-
Maryland	13	12	13	14	5	3	2	2	1	1	1	1
Massachusetts	53	56	57	67	13	9	9	7	3	3	5	3
Michigan	114	122	127	133	36	32	28	28	7	8	6	6
Minnesota	36	35	35	38	8	5	4	3	2	1	1	1
Mississippi	7	7	8	8	-	-	-	-	-	-	-	1
Missouri	28	30	29	33	6	5	3	4	-	-	1	2
Montana	2	2	2	4	-	-	-	-	-	-	-	-
Nebraska	7	8	8	8	1	-	-	-	-	-	-	-
Nevada	1	1	1	1	-	-	-	-	-	-	-	-
New Hampshire	8	5	4	8	2	1	-	-	1	1	1	1
New Jersey	45	44	48	56	12	10	10	9	2	1	1	2
New Mexico	-	1	2	1	-	-	-	-	-	-	-	-
New York	82	88	97	103	17	16	19	17	9	7	10	7
North Carolina	30	33	36	41	7	5	4	6	-	-	-	-
North Dakota	3	2	2	2	-	-	-	-	-	-	-	-
Ohio	151	162	159	163	61	52	46	46	16	18	16	18
Oklahoma	17	14	14	17	12	6	6	5	-	-	-	-
Oregon	13	16	17	16	5	7	7	6	-	-	-	1
Pennsylvania	155	183	189	198	48	43	41	34	16	14	13	14
Rhode Island	8	9	9	10	2	1	1	2	1	1	1	1
South Carolina	15	16	15	17	4	5	5	2	-	-	-	-
South Dakota	1	2	2	3	-	-	-	-	-	-	-	-
Tennessee	41	45	48	52	7	8	7	5	1	-	-	-
Texas	56	63	61	68	18	17	11	8	1	1	1	2
Utah	11	9	10	10	5	4	5	5	-	-	1	-
Vermont	8	8	10	10	1	-	-	-	-	-	-	1
Virginia	33	34	37	37	7	5	5	3	-	-	-	-
Washington	21	21	23	23	8	7	6	5	1	1	1	1
West Virginia	12	12	12	13	5	4	2	2	1	1	1	1
Wisconsin	84	82	85	87	28	25	23	22	10	10	11	11
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-
Total United States	1,571	1,653	1,712	1,837	459	387	361	328	93	93	95	104

Source: Foundry Magazine Census of Foundries.

EXHIBIT II-2

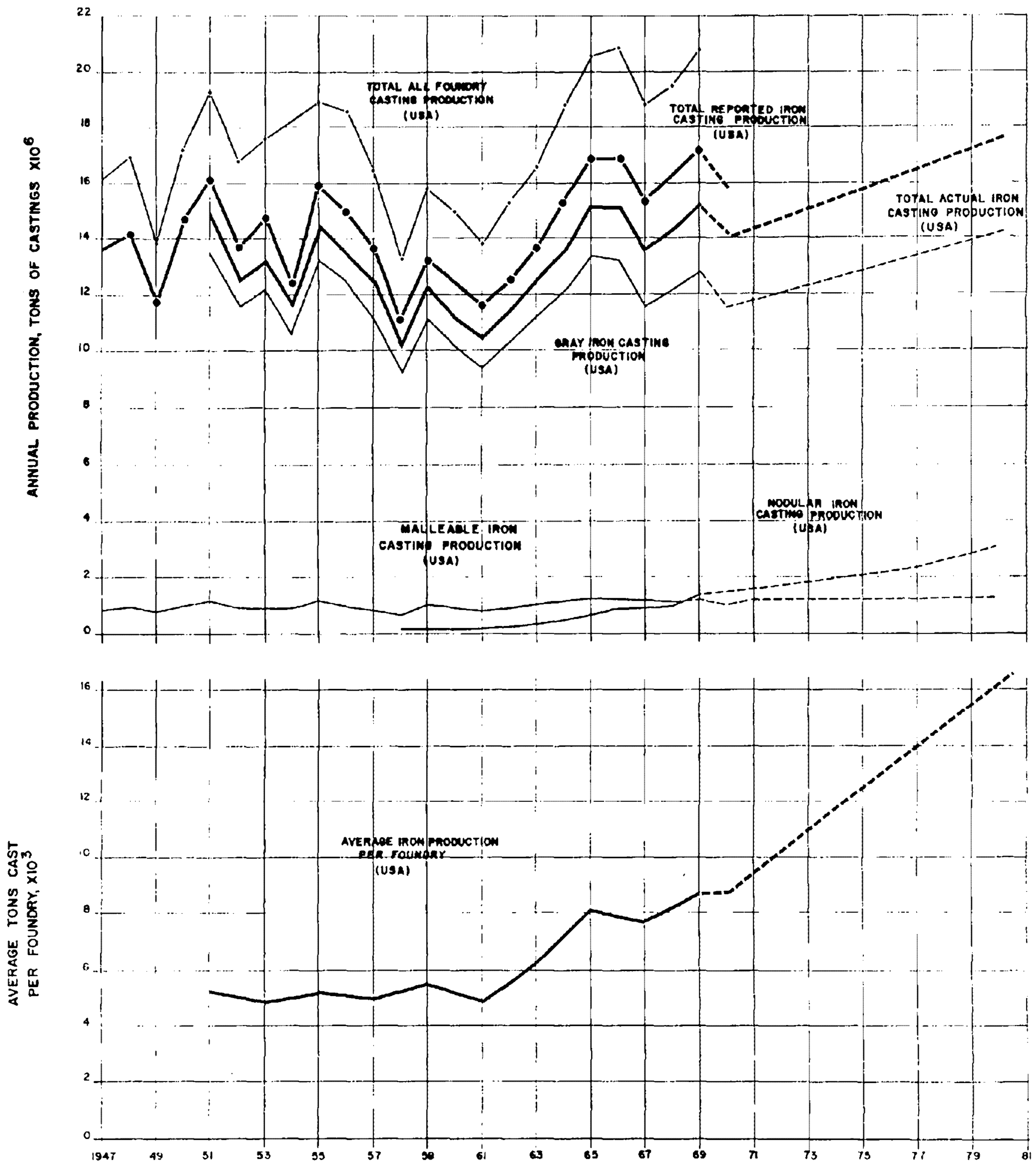
POPULATION TRENDS IN THE FOUNDRY INDUSTRY



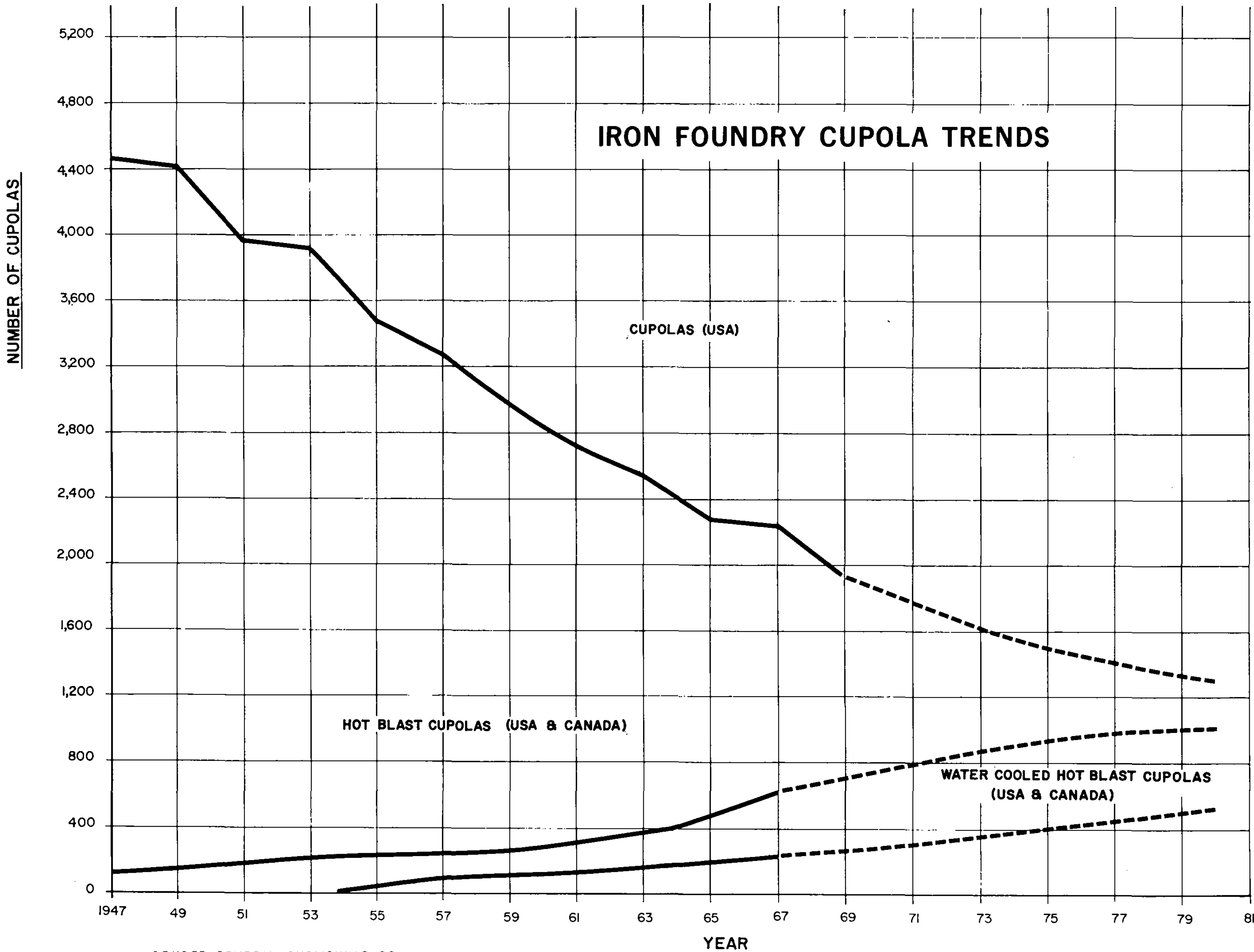
SOURCE: PENTON PUBLISHING CO.

EXHIBIT II-3

IRON FOUNDRY PRODUCTION TRENDS



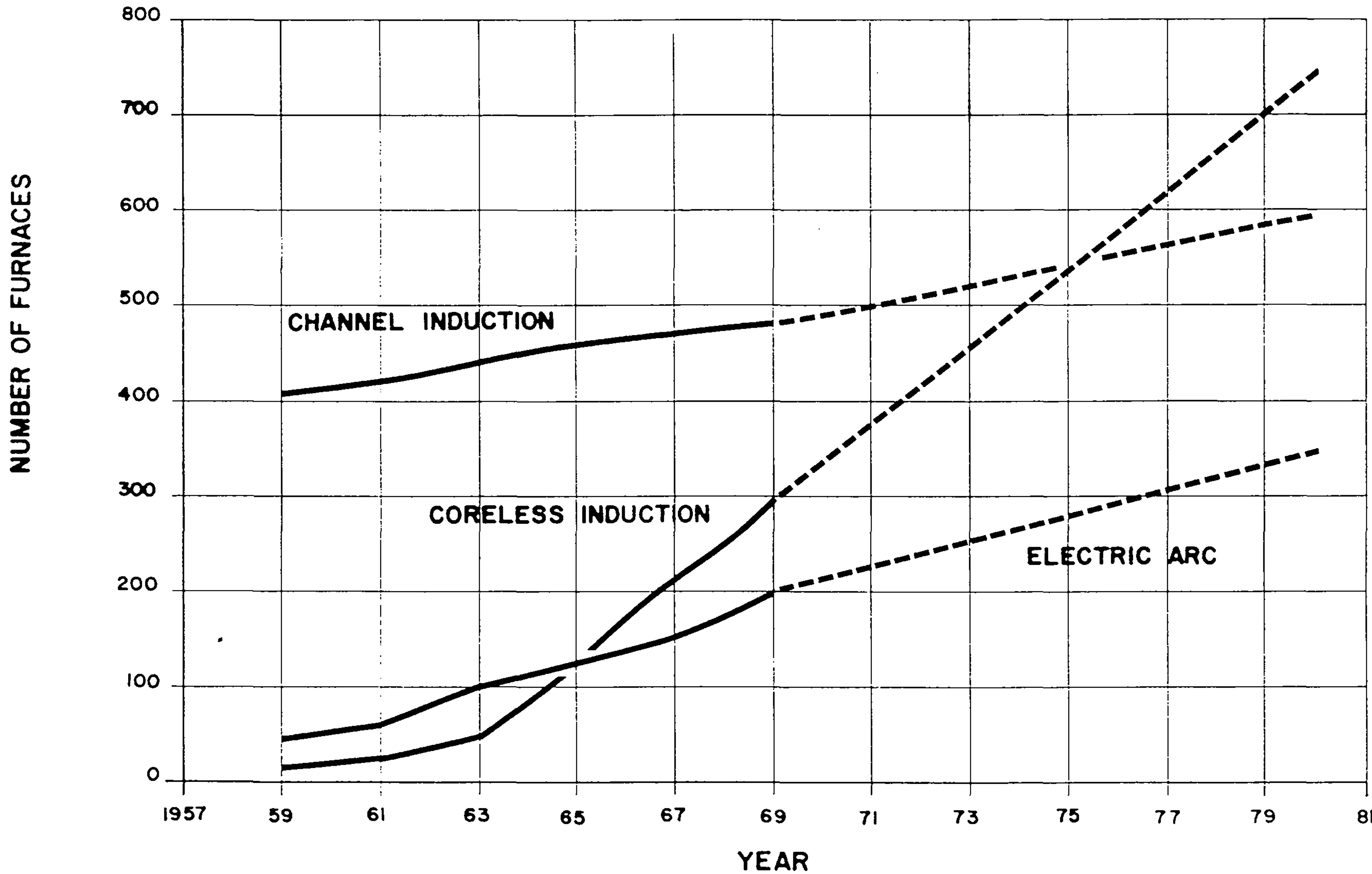
SOURCE: DEPARTMENT OF COMMERCE



SOURCE: PENTON PUBLISHING CO.

EXHIBIT II-5

IRON FOUNDRY ELECTRIC FURNACE TRENDS



SOURCE : DATA PROVIDED BY FURNACE MANUFACTURERS

EXHIBIT II-6

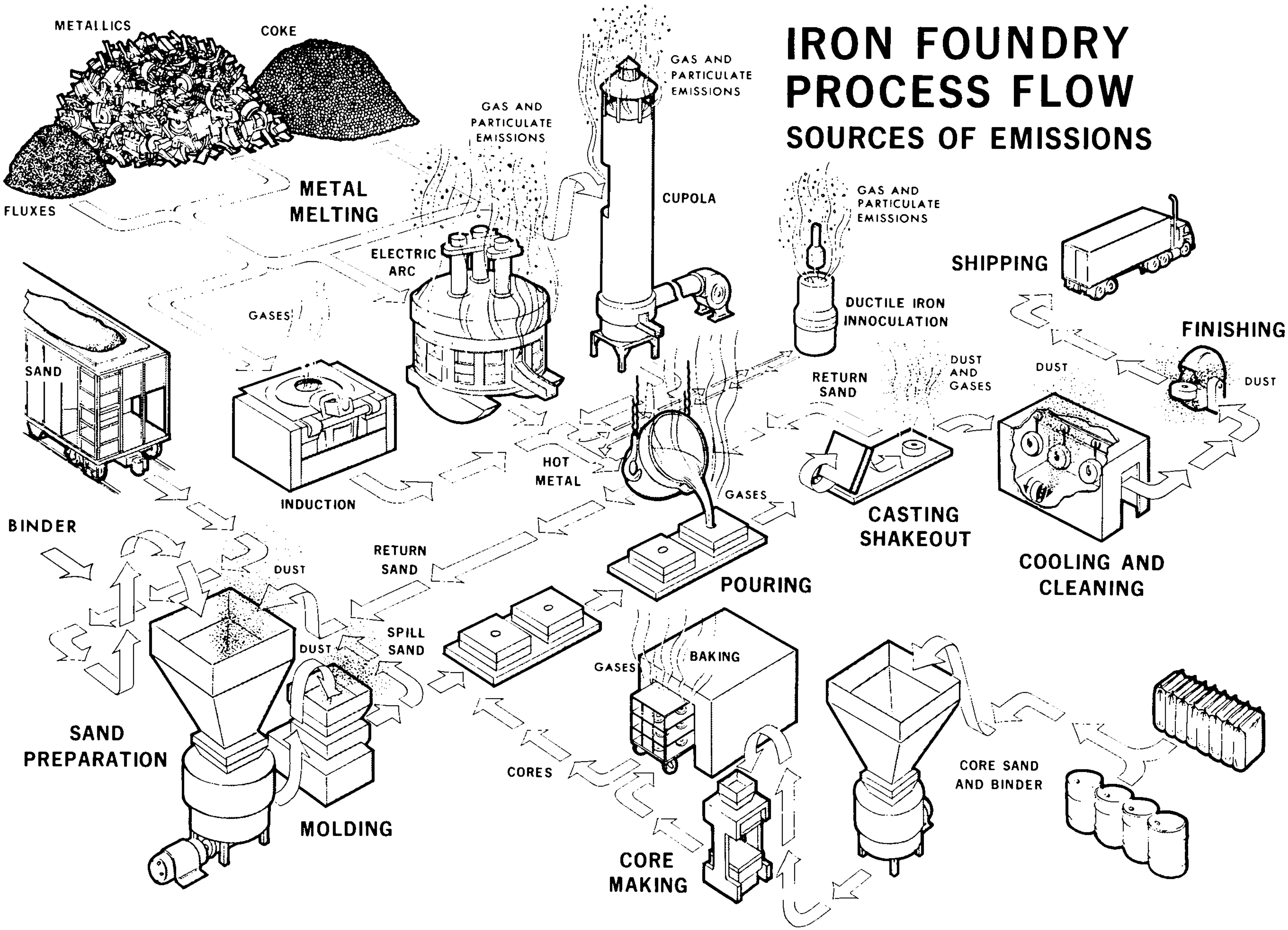
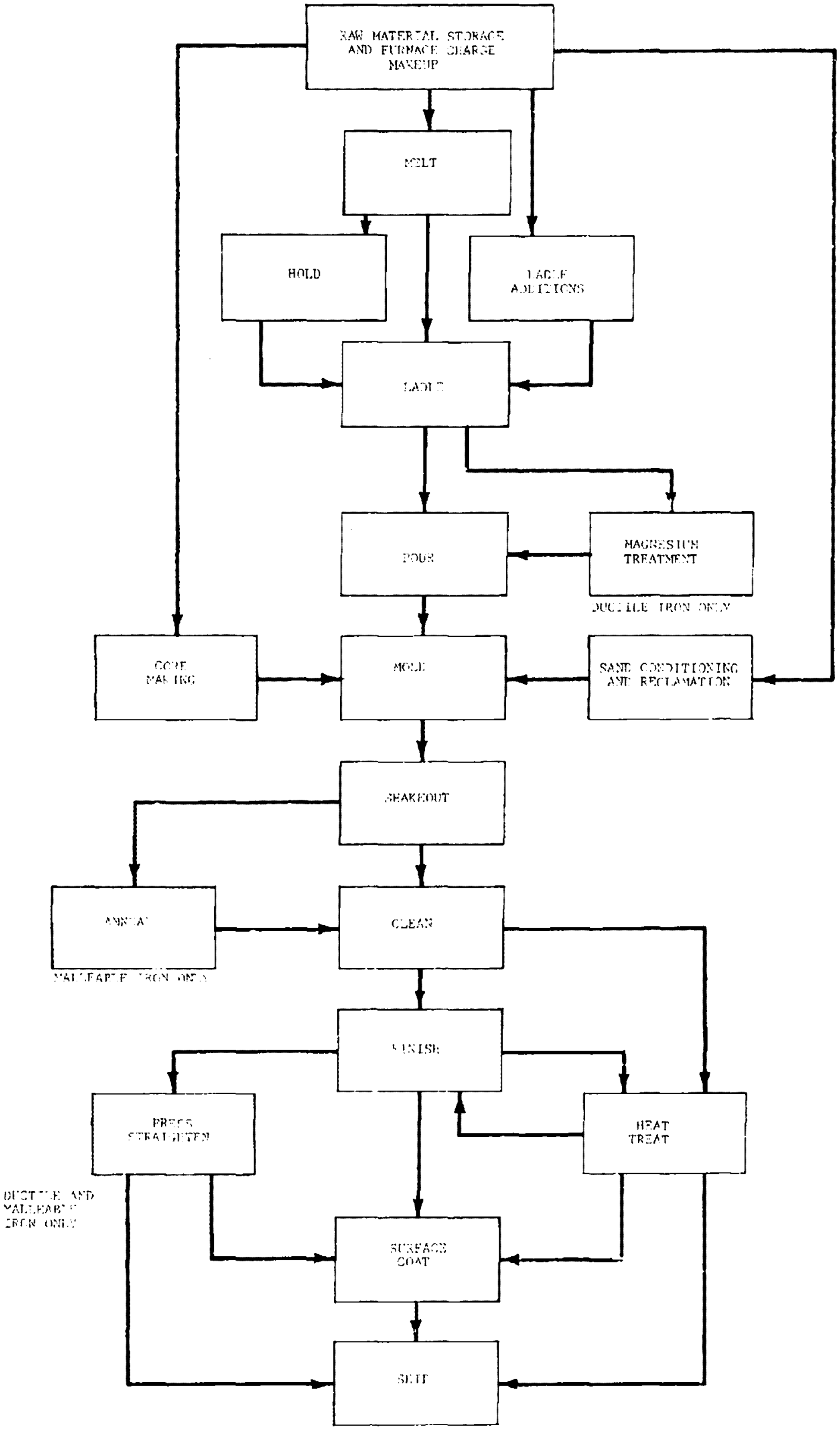


EXHIBIT III-1

PROCESS FLOW DIAGRAM

GRAY, DUCTILE AND MALLEABLE IRON



NOTE: ALL OPERATIONS APPLY TO GRAY, DUCTILE AND MALLEABLE IRON UNLESS OTHERWISE NOTED

SUMMARY OF GRAY IRON SPECIFICATIONS

Specifying Body	Specifying Number	Class	Tensile Strength Minimum PSI	Brinell Hardness		Total Carbon Percent		Silicon Percent	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
American Society for Testing and Materials	A159-62T	G2000(110)	20,000	-	187	3.40	3.70	2.30	2.80
		G3000(111)	30,000	170	223	3.20	3.50	2.00	2.30
		G3000a(113)	30,000	179	229	3.40	-	1.10	2.10
		G4000b(114)	40,000	207	269	3.40	-	1.10	1.80
Society of Automotive Engineers	J431a	G3500c(115)	35,000	187	241	3.50	-	1.10	1.80
		G3500(120)	35,000	187	241	3.10	3.40	1.90	2.20
		G4000(121)	40,000	202	255	3.00	3.30	1.80	2.10
General Services Administration	QQ-1-653	G4500(122)	45,000	217	269	3.00	3.30	1.80	2.10
		G4000d(123A)	40,000	248	311	3.10	3.40	2.10	2.40
		G4000e(123B)	40,000	248	311	3.10	3.45	2.10	2.40
		G4000f(123C)	40,000	248	311	3.40	3.75	2.10	2.35

Source: Gray and Ductile Iron Founders' Society, Inc.

EXHIBIT III-3

SUMMARY OF DUCTILE IRON SPECIFICATIONS

Specifying Body and Number	Use	Class or Grade	Tensile Strength Minimum PSI	Yield Strength Minimum PSI	Total Carbon Percent Min.	Total Carbon Percent Max.	Silicon Percent Min.	Silicon Percent Max.	Manganese Percent Min.	Manganese Percent Max.	Phosphorus Percent Min.	Phosphorus Percent Max.	Nickel Percent Min.	Nickel Percent Max.	Chromium Percent Min.	Chromium Percent Max.	Brinell Hardness Min.	Brinell Hardness Max.
American Society for Testing and Materials A439-62	Austenitic Ductile Iron Castings	D-2	58,000	30,000	-	3.00	1.50	3.00	.70	1.25	-	.08	18.00	22.00	1.75	2.75	139	202
		D-2B	58,000	30,000	-	3.00	1.50	3.00	.70	1.25	-	.08	18.00	22.00	2.75	4.00	148	211
		D-2C	58,000	28,000	-	2.90	1.00	3.00	1.80	2.40	-	.08	21.00	24.00	-	.50	121	171
		D-3	55,000	30,000	-	2.60	1.00	2.80	-	1.00	-	.08	28.00	32.00	2.50	3.50	139	202
		D-3A	55,000	30,000	-	2.60	1.00	2.80	-	1.00	-	.08	28.00	32.00	1.00	1.50	131	193
		D-4	60,000	-	-	2.60	5.00	6.00	-	1.00	-	.08	28.00	32.00	4.50	5.50	202	273
		D-5	55,000	30,000	-	2.40	1.00	2.80	-	1.00	-	.08	34.00	36.00	-	.10	131	185
		D-5B	55,000	30,000	-	2.40	1.00	2.80	-	1.00	-	.08	34.00	36.00	2.00	3.00	139	193
American Society for Testing and Materials A445-63T	Ferritic Ductile Iron Castings for Valves, Flanges, Pipe Flanges, Pipe Fittings and Other Piping Components	60-45-15	60,000	45,000	3.00	-	-	2.50	-	-	-	.08	-	-	-	-	149	201

Source: Gray and Ductile Iron Founders' Society, Inc.

EXHIBIT III-4

SUMMARY OF MALLEABLE IRON SPECIFICATIONS

TYPICAL COMPOSITION RANGES

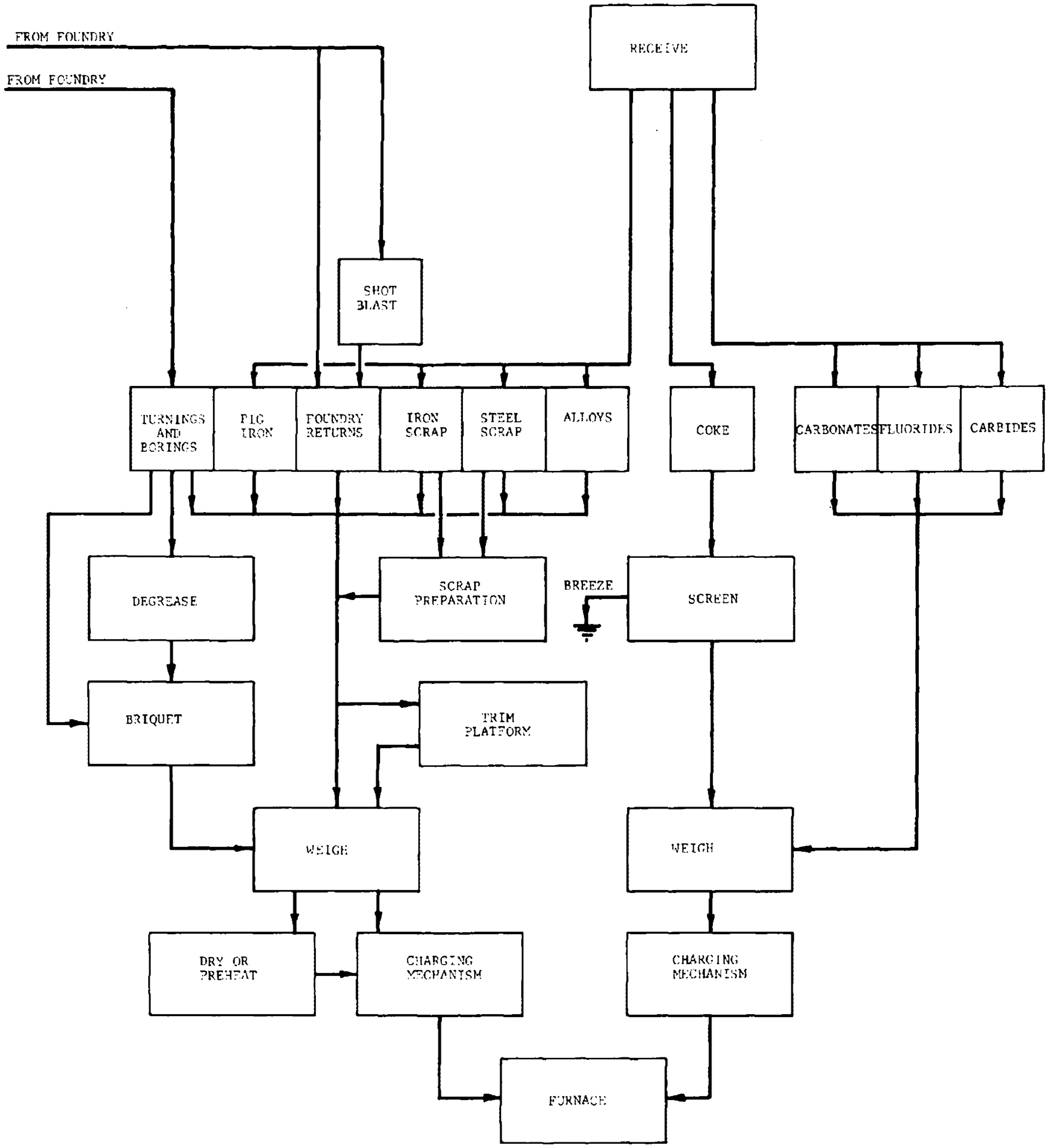
Type	Grade	Carbon Percent		Silicon Percent		Manganese Percent		Sulfur Percent		Phosphorus Percent	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Ferritic Malleable Iron	32510	2.30	2.65	.90	1.65	.25	.55	.05	.18	-	.18
	35018	2.00	2.45	.95	1.35	.25	.55	.05	.18	-	.18
Pearlitic Malleable Iron	-	2.00	2.65	.90	1.65	.25	1.25	.05	.18	-	.18

Source: American Society for Metals Handbook, Vol. 1, 1961.

EXHIBIT III-5

PROCESS FLOW DIAGRAM

RAW MATERIAL STORAGE AND FURNACE CHARGE MAKEUP



PROCESS FLOW DIAGRAM

MELTING DEPARTMENT

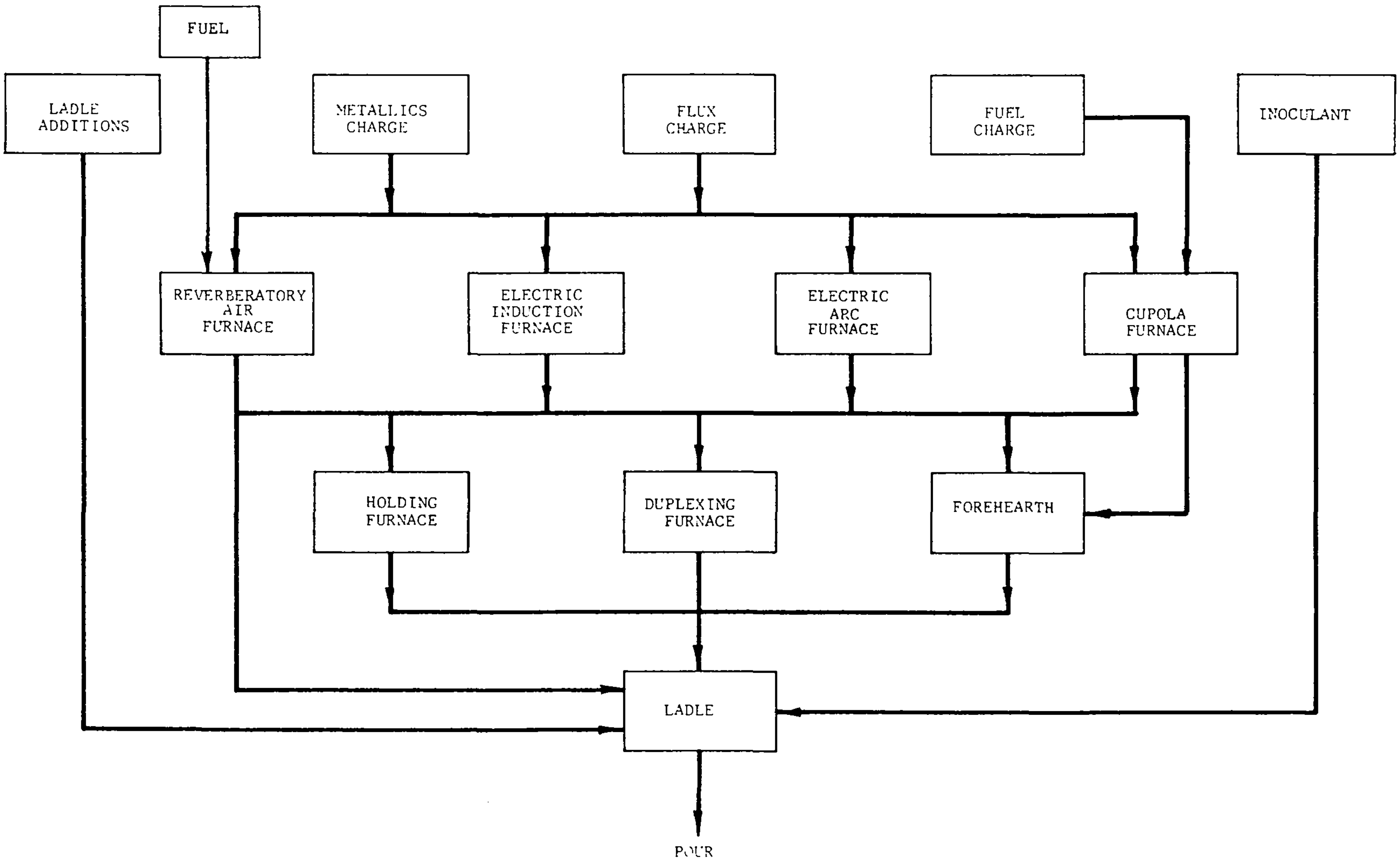
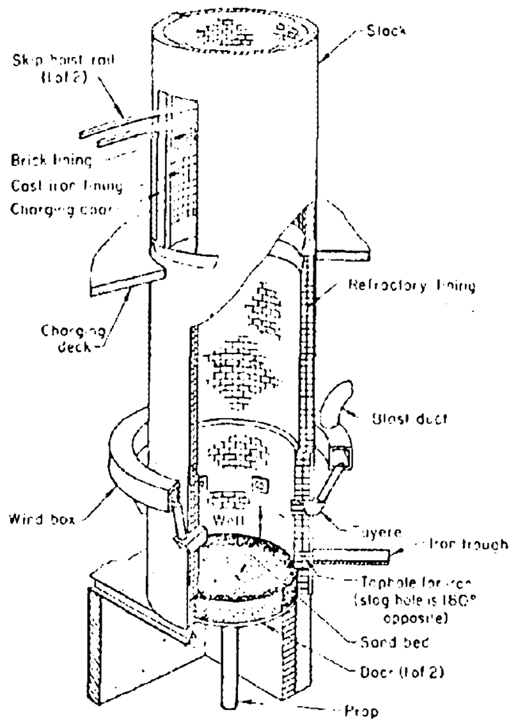


EXHIBIT III-7

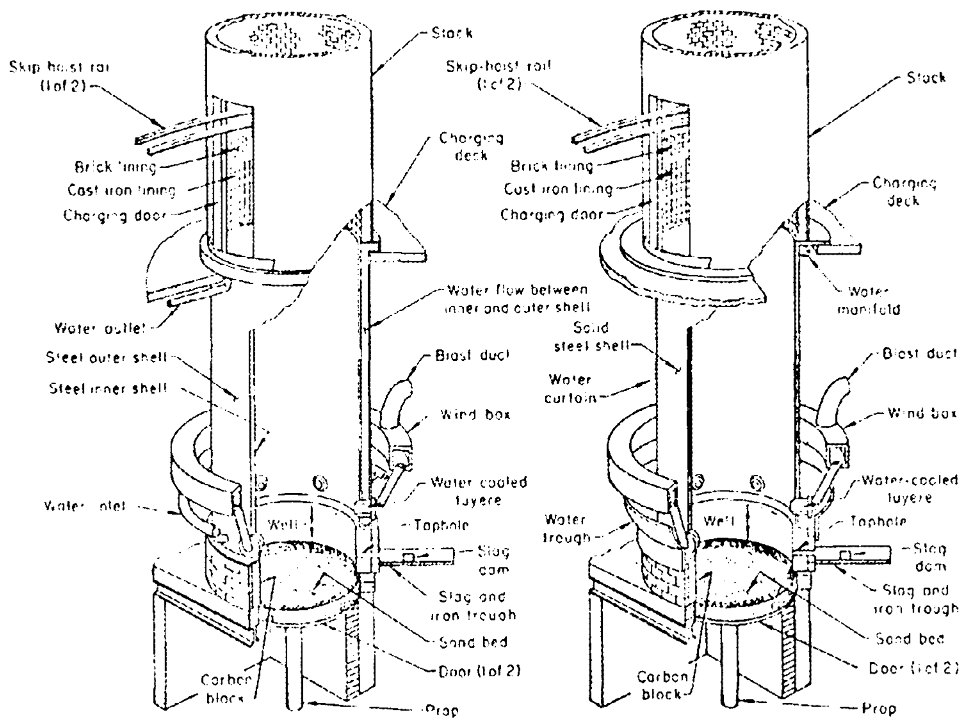
ILLUSTRATION OF CONVENTIONAL LINED CUPOLA



Conventional cupola

Source: Metals Handbook, 8th Edition, Vol. 5, Forging and Casting, American Society for Metals, 1970, p. 337.

ILLUSTRATION OF WATER-COOLED CUPOLA



Water-cooled cupola (water-wall)

Water-cooled cupola (flood cooled)

Source: Metals Handbook, 8th Edition, Vol. 5, Forging and Casting, American Society for Metals, 1970, p. 337.

APPROXIMATE MELTING RATES AND GAS VOLUMES FOR LINED CUPOLAS

FCE Lined Dia.	Melt Rate TPH Metal to Coke Ratio				Blast Air (SCFM)	Av. Chg. Door (Sq. Ft.)	Indraft (CFM)	Above-Door Total (SCFM)	Below-Door Total (SCFM)	Above Door (ACFM)	Below Door @ 850° F (ACFM)
	6/1	8/1	10/1	12/1							
18	3/4	1	-	-	570				650		2,000
23	1	1-1/2	-	-	940	10	3,000	3,940	1,050	7,700	3,000
27	1-3/4	2-1/4	-	-	1,290	10	3,000	4,290	1,450	8,500	4,000
32	2-1/2	3-1/4	4	-	1,810	10	3,000	4,810	2,000	10,800	5,000
37	3-1/4	4-1/4	5-1/4	-	2,420	11-1/4	3,380	5,800	2,700	13,100	7,000
42	4	5-1/2	7	-	3,100	16-1/2	4,950	8,050	3,500	18,100	9,000
45	4-1/2	6-1/4	8	-	3,600	22	6,600	10,200	4,000	23,000	12,000
48	5-1/2	7-1/4	9	10-3/4	4,100	45	13,500	17,600	4,600	34,500	16,000
54	7	9-1/4	11-1/2	13-3/4	5,200	50	15,000	20,200	5,800	39,500	18,000
60	9	11-1/4	14	17	6,400	50	15,000	21,400	7,100	42,500	20,000
66	10-1/2	13-3/4	17	20-1/2	7,700	52	15,600	23,300	8,500	51,000	23,000
72	12-1/4	16-1/4	20-1/4	24-1/2	9,200	52	15,600	24,800	10,500	56,000	28,000
78	15	19	23-3/4	28-3/4	10,700	60	18,000	28,700	12,000	65,000	32,000
84	17	22-1/4	27-3/4	33-1/4	12,500	63	18,900	31,400	14,000	71,000	37,000

Adapted from Useful Information for Foundrymen published by Whiting Corporation.

Assumptions:
1. No door closure
2. No oxygen enrichment
3. No fuel injection
4. Indraft at 300 FPM

APPROXIMATE MELTING RATES AND
GAS VOLUMES FOR UNLINED CUPOLAS

FCE Dia.	Melt Rate TPH Metal to Coke Ratio (1000° F Hot Blast)						Blast Air (SCFM)	Av. Chg. Door (Sq. Ft.)	Indraft (CFM)	Above-Door Total (SCFM)	Below-Door Total (SCFM)	Above Door (ACFM)	Below Door @ 850° F (ACFM)
	5/1	6/1	7/1	8/1	9/1	10/1							
36	4-1/2	4-3/4	5	5-1/2	5-3/4	6-1/4	2,300	12	3,600	5,900	2,600	13,300	7,000
42	6-1/4	6-1/2	6-3/4	7-1/4	7-3/4	8-1/4	3,100	16-1/2	4,950	8,050	3,500	18,100	9,000
48	8	8-1/4	9	9-3/4	10-1/2	11-1/4	4,100	45	13,500	17,600	4,600	34,500	16,000
54	10	10-1/2	11-1/2	12-1/4	13-1/4	14-1/4	5,200	50	15,000	20,200	5,800	39,500	18,000
60	12-1/2	13	13-1/2	15-1/4	16-1/4	17-1/4	6,400	50	15,000	21,400	7,100	41,500	20,000
66	15	15-1/2	17	18-1/4	19-3/4	20-3/4	7,700	52	15,600	23,300	8,500	51,000	23,000
72	17-3/4	18-1/2	20	22	23-1/4	25	9,200	60	18,000	27,200	10,500	59,200	28,000
78	20-3/4	21-3/4	23-1/4	25-1/2	27-1/4	29	10,700	60	18,000	28,700	12,000	65,000	32,000
84	24-1/4	25-1/4	27-1/4	29-1/4	32	34	12,500	63	18,900	31,400	14,000	71,000	37,000
90	27-3/4	29	31-1/2	34-1/4	36-1/4	39	14,300	95	28,500	42,800	16,000	93,000	42,000
96	31-3/4	33	34-1/2	39	41-1/2	44	16,300	110	33,000	49,300	18,000	105,000	48,000
102	36	37-1/4	40-1/2	44	47	50	18,400	120	36,000	54,400	21,000	115,000	56,000
108	40	41-1/2	45	49	52-1/2	56	20,600	128	38,400	59,000	23,000	128,000	62,000

Adapted from Useful Information for Foundrymen published by Whiting Corporation.

Assumptions:
1. No door closure
2. No oxygen enrichment
3. No fuel injection
4. Indraft at 300 FPM

EXHIBIT III-11

ILLUSTRATION OF CUPOLA REACTION AREA

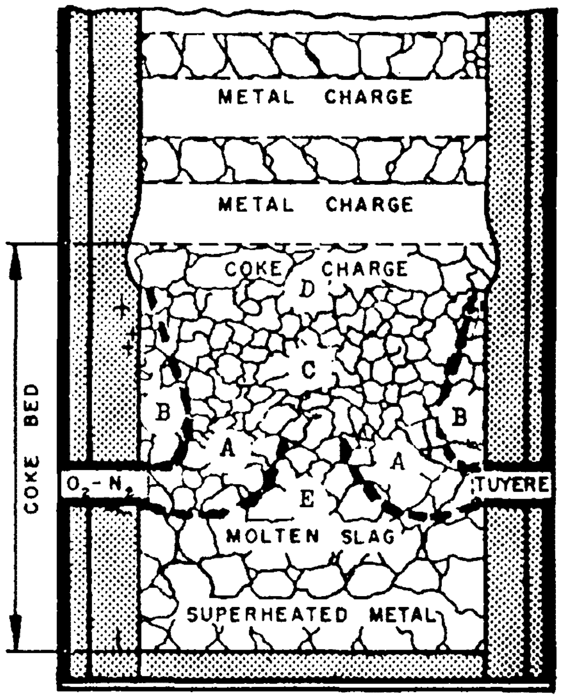


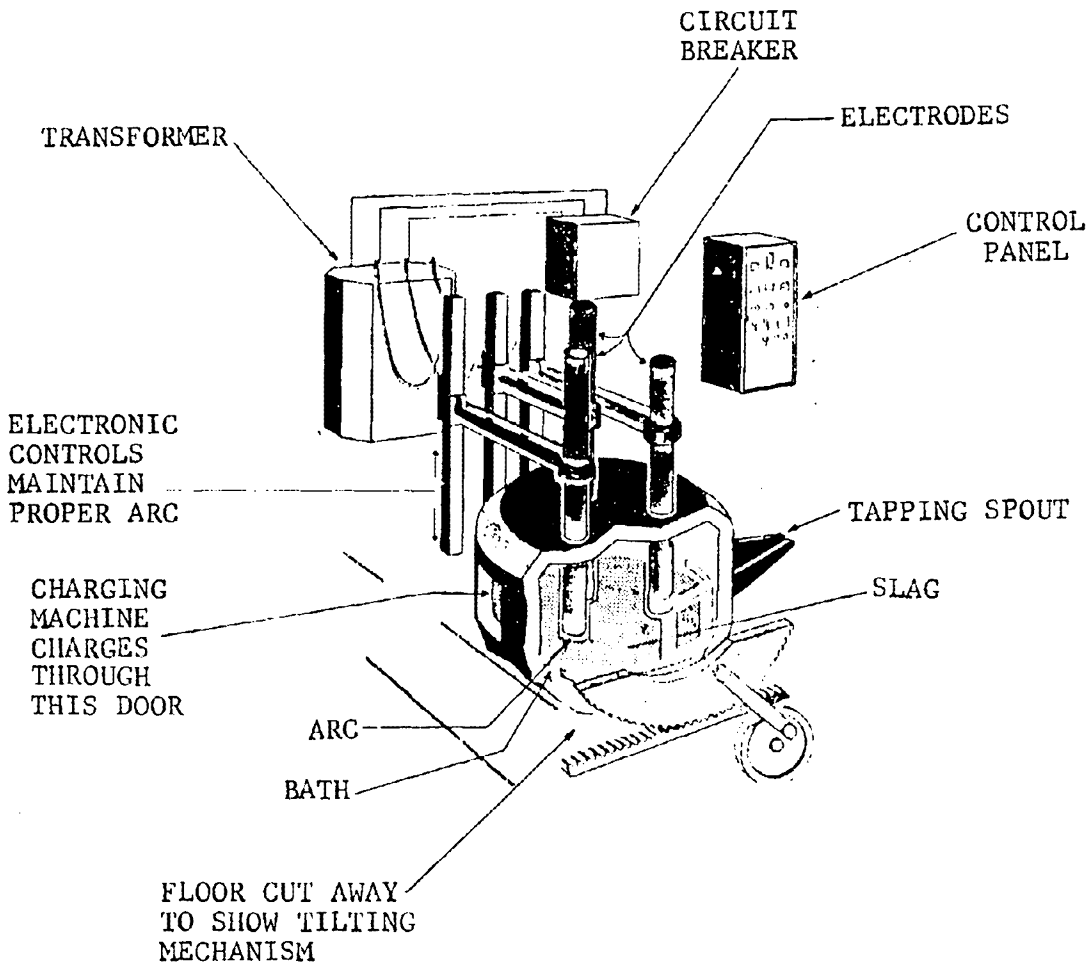
Fig. 3.3. Cross-section of cupola showing reaction areas.
A — $O_2 + CO_2$
B — Area high in O_2
C — $CO + CO_2$
D — High $CO : CO_2$ ratio
E — High $CO : CO_2$ ratio

Source: The Cupola and Its Operation; published by the American Foundrymen's Society, Third Edition, 1965, p. 26.

TYPICAL CUPOLA MATERIAL BALANCE

Lined Cupola			Water-Cooled Cupola		
Inputs	Pounds	Percent	Inputs	Pounds	Percent
Metal Charge	2,004	52.08%	Metal Charge	1,992	47.42%
Pig Iron	0	0.00	Pig Iron	233	5.56
Returns	802	20.83	Returns	996	23.71
Steel Scrap	1,137	29.56	Steel Scrap	739	17.60
Iron Scrap	0	0.00	Iron Scrap	0	0.00
Ferroalloys	65	1.69	Ferroalloys	23	0.56
Coke	167	4.33	Coke	253	6.03
Natural Gas	29	0.75	Natural Gas	0	0.00
Fuel Oil	0	0.00	Fuel Oil	0	0.00
Flux and Additives	65	1.69	Flux and Additives	58	1.38
Air	1,556	40.43	Air	1,898	45.18
Oxygen	0	0.00	Oxygen	0	0.00
Cupola Lining	27	0.71	Cupola Lining	0	0.00
Total Input Materials	3,848	100.00%	Total Input Materials	4,201	100.0%
Outputs			Outputs		
Molten Iron	2,000	51.97%	Molten Iron	2,000	47.60%
Slag	32	0.83	Slag	44	1.04
Emissions Dust	14	0.37	Emissions Dust	19	0.45
Top Gases	1,802	46.84	Top Gases	2,139	50.90
Nitrogen	1,188	65.91	Nitrogen	1,449	67.77
Carbon Dioxide	507	28.10	Carbon Dioxide	468	21.87
Carbon Monoxide	99	5.49	Carbon Monoxide	220	10.29
Hydrogen	9	0.47	Hydrogren	2	0.07
Sulfur Dioxide	0	0.02	Sulfur Dioxide	-0	-0.00

ILLUSTRATION OF ELECTRIC ARC FURNACE



Source: The Picture Story of Steel, published by the American Iron and Steel Institute, 1952, p. 18.

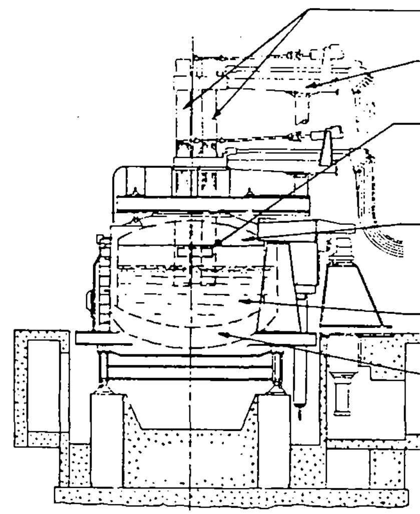
HEAT BALANCE

	BTU/Ton (x1000)	Percent
Input Heat		
Electrical Energy	1,907	100.0
Output Heat		
Melting and Superheating Iron	1,132	59.3
Heat Content of Slag	81	4.3
Decomposition of Water	9	.5
Gases		
Sensible Heat	231	12.1
Latent Heat	-138	- 7.2
Heat, Electrical and Cooling Losses	592	31.0
Total	1,407	100.0

MATERIAL BALANCE

	Pounds	Percent
Input Material		
Returns	1,388	56.9
Steel Scrap	630	25.8
Ferroalloys	17	.7
Carbo-Coke	31	1.3
Electrodes	10	.4
Air	318	13.0
Moisture	8	.3
Lining	38	1.6
Total	2,440	100.0
Output Material		
Molten Iron	1,997	81.8
Slag	93	3.8
Particulate Emissions	14	.6
Gaseous Emissions	336	13.8
Total	2,440	100.0

NOTE: Energy quantities include only theoretical requirements for heating, melting, and superheating to 2800° F, and normal electrical, transmission and heat losses. The total is less than the average used in normal practice since it does not include allowances for holding, or normal operating delays.

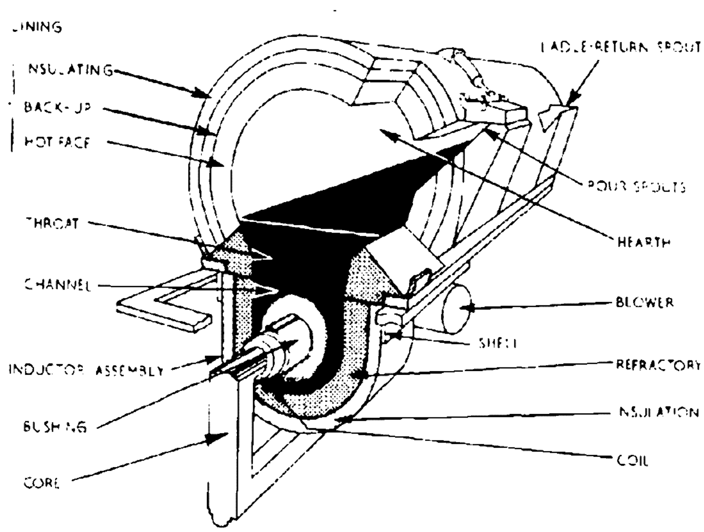


ELECTRIC ARC FURNACE - HEAT AND MATERIAL BALANCE

EXHIBIT III-15

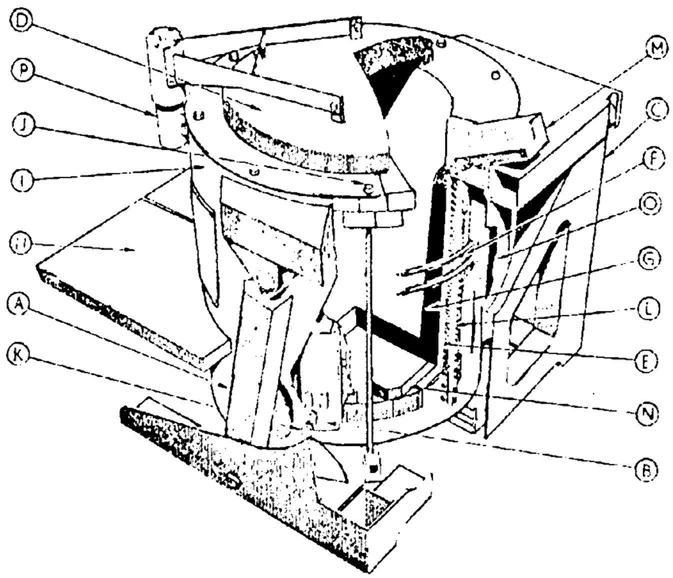
EXHIBIT III-16

ILLUSTRATION OF CHANNEL INDUCTION FURNACE



Source: "Electric Melting for Mass Production in U.S. Iron Foundries," Modern Casting, July, 1968, p. 47.

ILLUSTRATION OF CORELESS INDUCTION FURNACE



A. HYDRAULIC TILT CYLINDERS
B. SHUNTS
C. STANCHION
D. COVER
E. COIL
F. LEADS
G. WORKING REFRACTORY
H. OPERATOR'S PLATFORM

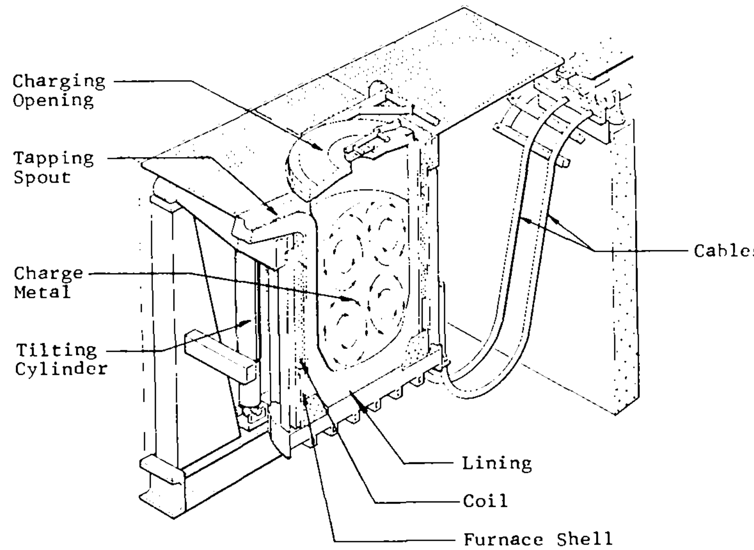
I. STEEL SHELL
J. TIE RODS
K. CLAMPING BOLTS
L. COIL SUPPORT
M. SPOUT
N. REFRACTORY BRICK
O ACCESS PORT
P. LID HOIST MECHANISM

Source: "Electric Melting for Mass Production in U.S. Iron Foundries," Modern Casting, July, 1968, p. 47.

HEAT BALANCE	BTU/TON (x 000)	PERCENT
INPUT HEAT		
ELECTRICAL ENERGY	1,669	100.0
OUTPUT HEAT		
MELTING AND SUPER-HEATING IRON	1,131	68.4
ELECTIRCAL LOSSES	325	19.1
TRANSMISSION LOSSES	81	4.7
HEAT LOSS	132	7.8
TOTAL	1,669	100.0

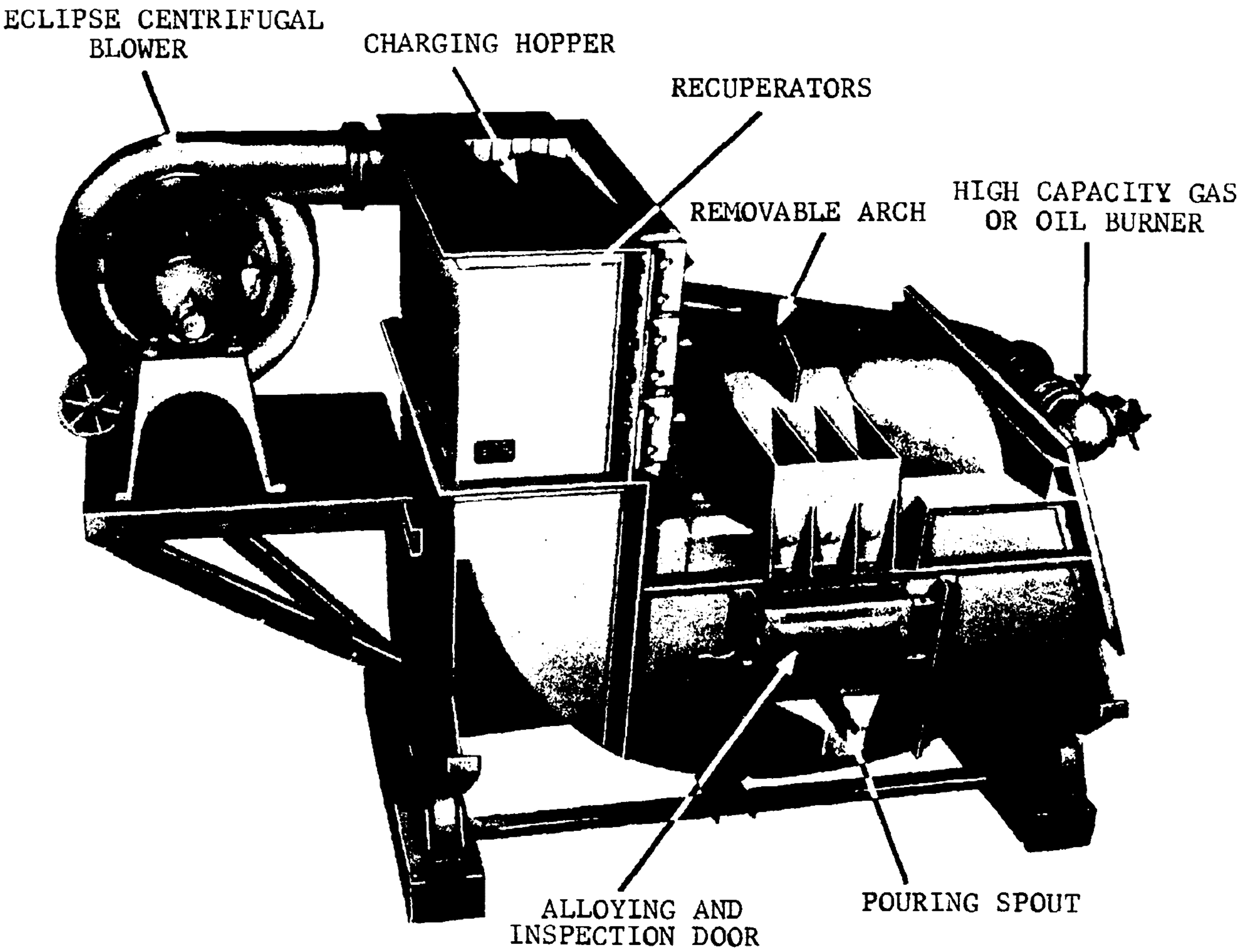
NOTE: ENERGY QUANTITIES INCLUDE ONLY THEORETICAL REQUIREMENTS FOR HEATING, MELTING, AND SUPERHEATING TO 2800° F, AND NORMAL ELECTRICAL, TRANSMISSION AND HEAT LOSSES. THE TOTAL IS LESS THAN THE AVERAGE USED IN NORMAL PRACTICE SINCE IT DOES NOT INCLUDE ALLOWANCES FOR HOLDING, OR NORMAL OPERATING DELAYS.

MATERIAL BALANCE	POUNDS	PERCENT
INPUT MATERIALS		
RETURNS	378	18.6
STEEL SCRAP	1,351	66.7
IRON CHIPS	188	9.3
FERROALLOYS	43	2.1
LINING	6	.3
CARBO-COKE	61	3.0
TOTAL	2,027	100.0
OUTPUT MATERIALS		
MOLTEN IRON	2,000.0	98.7
SLAG	10.0	.5
EMISSIONS		
GASEOUS	15.5	.7
PARTICULATE	1.5	.1
TOTAL	2,027.0	100.0



CORELESS INDUCTION FURNACE - HEAT AND MATERIAL BALANCE

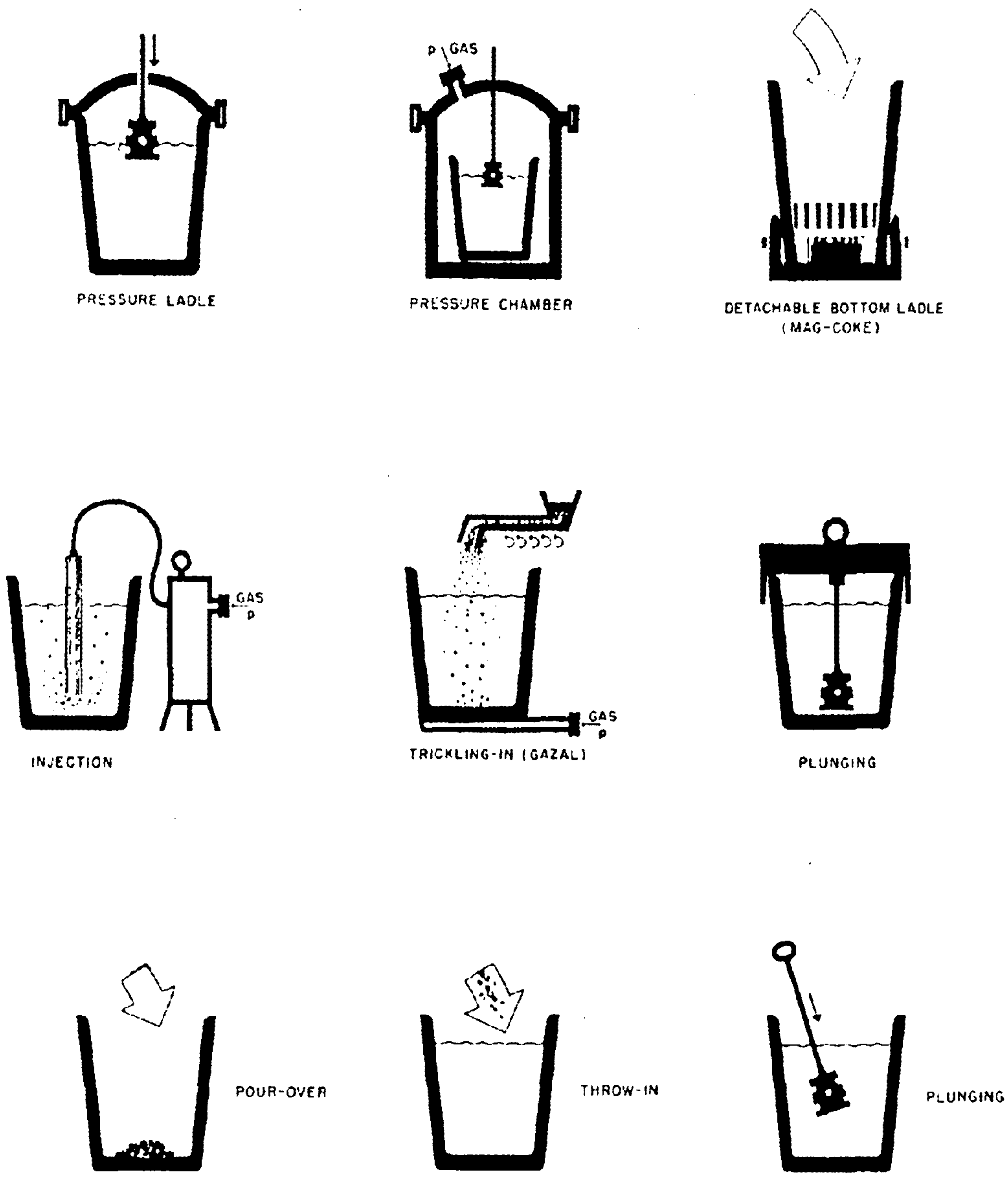
ILLUSTRATION OF REVERBERATORY FURNACE



Source: The Wheelabrator Corporation.

EXHIBIT III-20

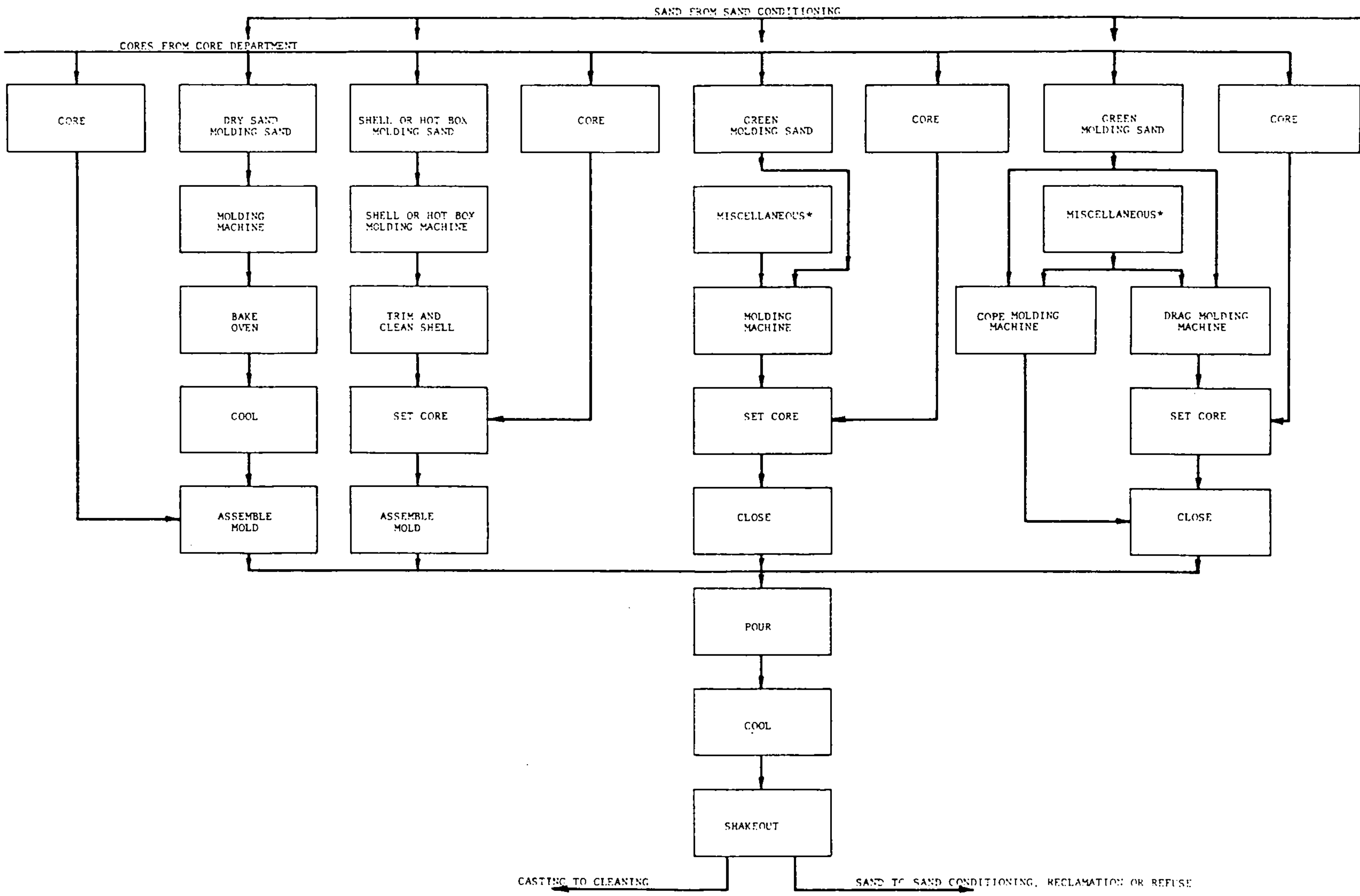
ILLUSTRATION OF MAGNESIUM TREATMENT METHODS FOR PRODUCING DUCTILE IRON



Source: "Comparing Processes for Making Ductile Iron," E. Modl, FOUNDRY, July, 1970, pp. 44-46.

PROCESS FLOW DIAGRAM

MOLDING, POURING & SHAKEOUT



* MISCELLANEOUS - PARTING COMPOUND, WASH, CHAPLETS, ETC.

EXHIBIT III-21

PROCESS FLOW DIAGRAM

CLEANING & FINISHING

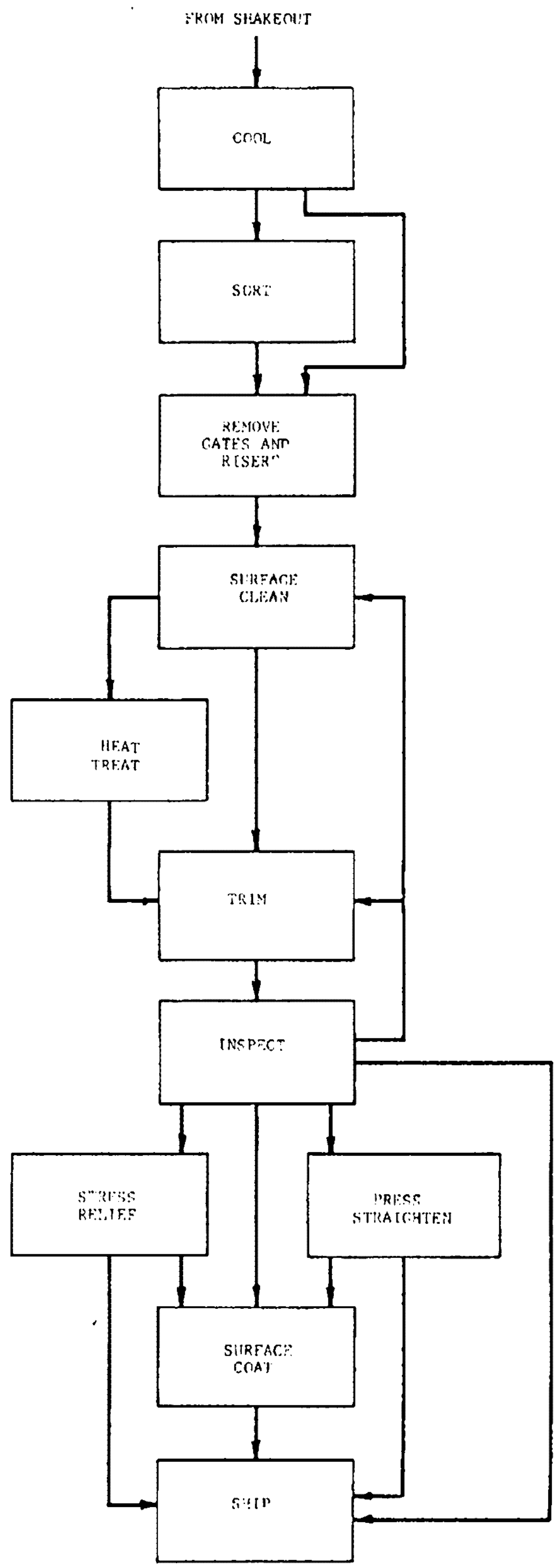
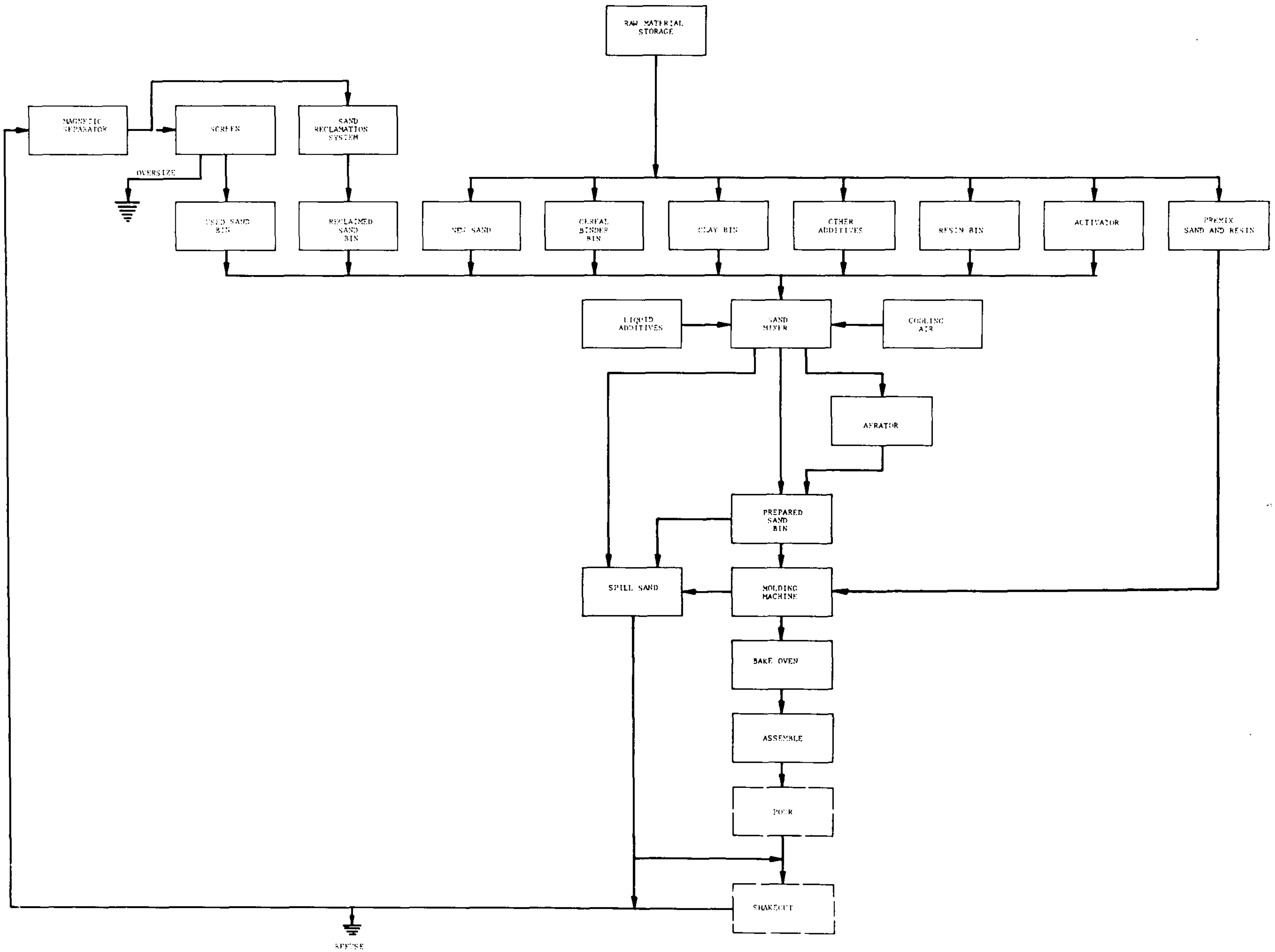


EXHIBIT III-23

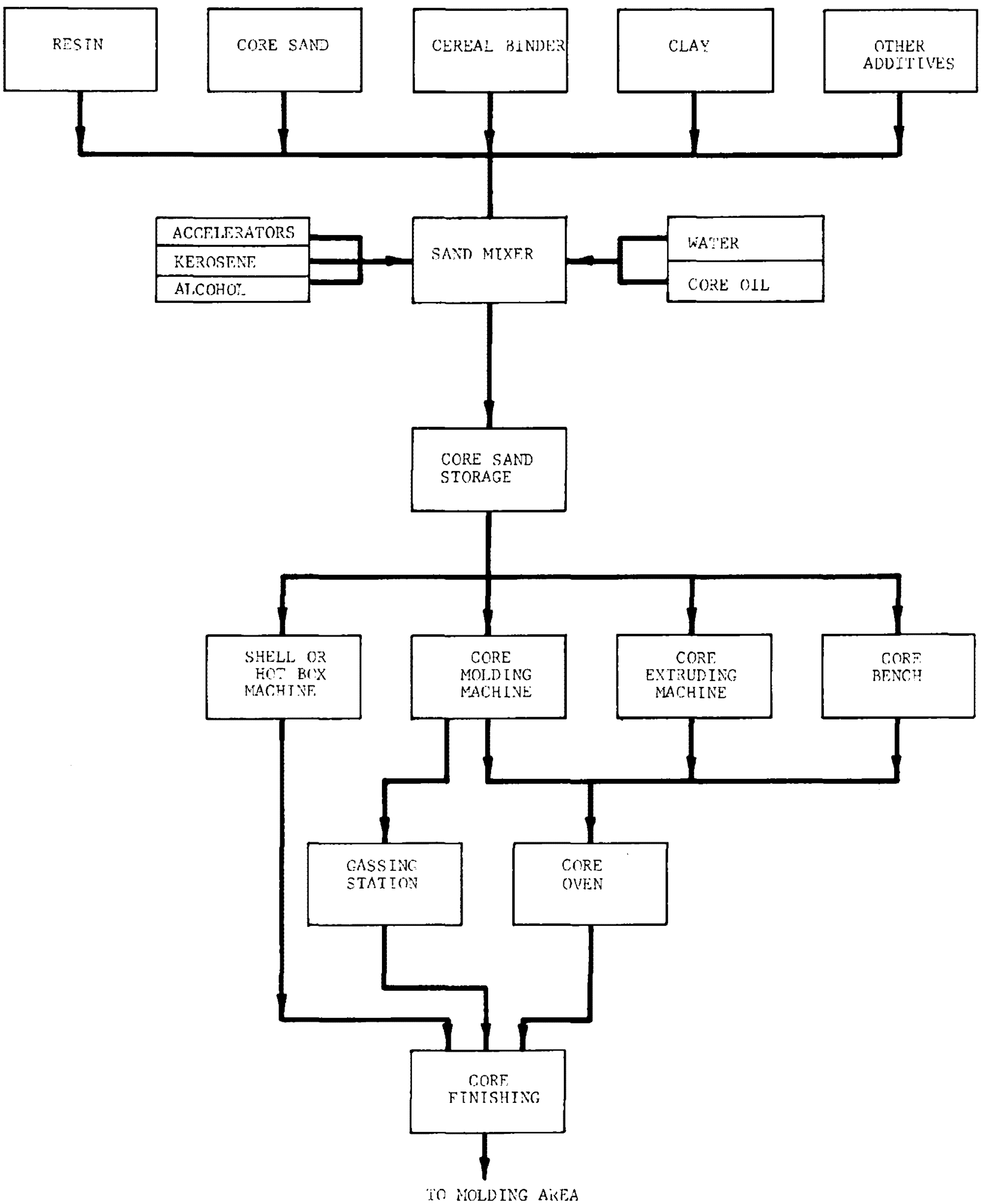
PROCESS FLOW DIAGRAM

SAND CONDITIONING



PROCESS FLOW DIAGRAM

CORE MAKING



CHARACTERISTICS AND SOURCES OF EMISSIONS IN VARIOUS FOUNDRY DEPARTMENTS

DEPARTMENT	OPERATION	EMISSIONS: TYPE	EMISSIONS: CONCENTRATION	EMISSIONS: PARTICLE SIZE (Microns)
RAW MATERIAL STORAGE AND CHARGE MAKEUP	Store metal scrap, coke, limestone, dolomite, fluorspar, silica sand.	Dust: Coke, limestone and sand.	3 to 5gr./cu.ft. Moderate	Fine to coarse 30 to 1,000
	Centrifuge or heat metal borings and turnings to remove cutting oil	Oil vapors	Light	.03 to 1
		Smoke	Light	.01 to .4
		Unburned hydrocarbons	Light	
	Weigh charge materials	Coke dust Limestone dust	3 to 5gr./cu.ft. Moderate	Fine to coarse 30 to 1,000
MELTING	Cupola furnace melting	Fly ash, dust	.2 to 5gr./cu.ft.	8 to 20
		Coke breeze	5gr./cu.ft. & up	Fine to coarse
		Smoke	Heavy	.01 to .4
		Metallic oxides	Moderate to heavy	To .7
		Sulfur compounds	Light	
		Oil vapors	Light	.03 to 1
		Carbon monoxide	Heavy	-
	Electric furnace melting	Smoke	Heavy	.01 to .4
		Metallic oxides	Moderate	To .7
		Oil vapors	Heavy	.03 to 1
	Induction furnace melting	Oil vapors, metallic oxides		
	Reverberatory (Air) furnace	Smoke	Moderate	.01 to .4
		Oil vapors	Moderate	.03 to 1
		Metallic oxides	Moderate	To .7
		Fly ash, sulfur compounds	.2 to 5gr./cu.ft.	8 to 20
	Furnace charge preheating or drying	Smoke, dust	Light to heavy	.01 to .4
		Oil vapors	Light to heavy	.03 to 1
		Metallic oxides	1.24#/ton	75%-5 to 60 bottom fired
		Metallic oxides	.41#/ton	0 to 20 top fired
	Holding furnaces	Iron oxide	Light	Fine to medium
		Oil vapor	Light	.03 to 1
	Duplexing furnaces	Oil vapor	Light	.03 to 1
		Metallic oxides	Light	To .7
	Inoculation	Metallic oxides	Heavy	To 0.7
MOLDING, POURING AND SHAKEOUT	Molding	Dust, mist Vapor	Light	Coarse

CHARACTERISTICS AND SOURCES OF EMISSIONS IN VARIOUS FOUNDRY DEPARTMENTS

DEPARTMENT	OPERATION	EMISSIONS		
		TYPE	CONCENTRATION	PARTICLE SIZE (Microns)
MOLDING, POURING AND SHAKEOUT (Cont'd)	Pouring			
	Gray and ductile iron	Core gases	Heavy	
	Malleable	Facing fumes	Heavy	
		Metallic oxides	Light	Fine to medium
		Fluoride fumes	Heavy	
		Magnesium oxide fumes	Heavy	.01 to .4
		Synthetic binder Smoke and fumes	Moderate to heavy	
	Shakeout	Dust	3 to 5gr./cu.ft.	50%-2 to 15
		Smoke	Heavy	.01 to .4
		Steam	Heavy	
CLEANING AND FINISHING	Abrasive cleaning	Dust	3gr./cu.ft.& up	50%-2 to 15
	Grinding	Metal dust	5gr./cu.ft.& up	Above 7
		Sand dust	3 to 5gr./cu.ft.	Fine to medium
		Abrasive dust	.5 to 2gr./cu.ft.	50%-2 to 7
		Wheel bond material	Light	Fine
		Vitrified resins	Light	50%-2 to 15
	Annealing and heat treating	Oil vapors, gas products of combustion		.03 to 1
	Painting	Solvent vapors		
	Spray and dip	Paint spray carry-over	.5 to 2gr./cu.ft	50%-2 to 7
		Water spray carry-over		
SAND CONDITIONING	New sand storage	Dust	3 to 5gr./cu.ft.	50%-2 to 15
	Sand handling system	Dust	3 to 5gr./cu.ft.	50%-2 to 15
		Steam		
	Screening	Dust	3 to 5gr./cu.ft.	50%-2 to 15
	Mixing	Dust	3 to 5gr./cu.ft.	50%-2 to 15
		Flour	Moderate	Fine to medium
		Bentonites	Moderate	Fine to medium
		Sea coal	Moderate	Fine to medium
		Cellulose	Moderate	Fine to medium
	Drying and reclamation	Dust	1/2 to 2gr./cu.ft.	50%-7 to 15
		Core gases		.03 to 1

CHARACTERISTICS AND SOURCES OF EMISSIONS IN VARIOUS FOUNDRY DEPARTMENTS

DEPARTMENT	OPERATION	EMISSIONS		
		TYPE	CONCENTRATION	PARTICLE SIZE (Microns)
COREMAKING	Sand storage	Dust Flour Binders	Heavy 3 to 5gr./cu.ft.	Fine 50%-7 to 15
	Coremaking	Resin dust Sand dust	Heavy Light	Fine to medium Fine to medium
	Baking	Vapors, gases Smoke	-	-

CHEMICAL COMPOSITION OF CUPOLA PARTICULATE EMISSIONS

Foundry Number	Percent by Weight in Cupola Effluent								
	Iron Oxide	Magnesium Oxide	Manganese Oxide	Lead Oxide	Aluminum Oxide	Zinc Oxide	Silicon Dioxide	Calcium Oxide	Combustibles
66	11.1%						12.3%		
85	14.7	1.3%		1.4%			28.7		24.0%
90							56.3	42.0%	0.9
113	8.6		3.7%		.05%		31.8	3.1	27.0
116	10.0	5.0	10.0		5.0	1.0%	10.0	3.0	5.0
146	33.0		1.0	5.0		38.0	20.0	1.0	
150	11.6	1.0	5.5	20.0	1.4	14.7	30.1	1.1	

Note: Quantities as reported. They do not add up to 100%.

PARTICLE SIZE DISTRIBUTION-CUPOLA EMISSIONS

Foundry	Cumulative Percent by Weight — Diameter in Microns							
	-1	-2	-5	-10	-20	-50	-100	-200
9		30%	50%	65%	82%	90%	99%	
14		64	82	98	99			
18			2	12	34	92	99	99%
26		13	28	45	55	60		
32			54	86	98	99	99	99
67			14	15	15	21	99	
67					19	25	99	
146						99	99	
151		0.6	2	3	8	99	99	
A[1]			4	5.5	7	13.7	75	80
B[1]			11	13	32	53	75	94
C[1]			8	12	17	28	69	89
1[2]			18	25	38	62		
2[2]			17	26	36	53		
3[2]			24	28	23	42		
4[2]			26	30	32	44		
A[2]	0	7	25	32	34	41	56	61
B[2]	0	7	24	41	47	32	69	81

Sources:

1. The Cupola and Its Operation, Third Edition, 1965, American Foundrymen's Society, p. 82.

2. Air Pollution Engineering Manual, Public Health Service Publication, No. 999-AP-40, 1967 Department of Health, Education, and Welfare.

PARTICULATE EMISSIONS
VS. SPECIFIC BLAST RATE
FOR ACID LINED CUPOLAS

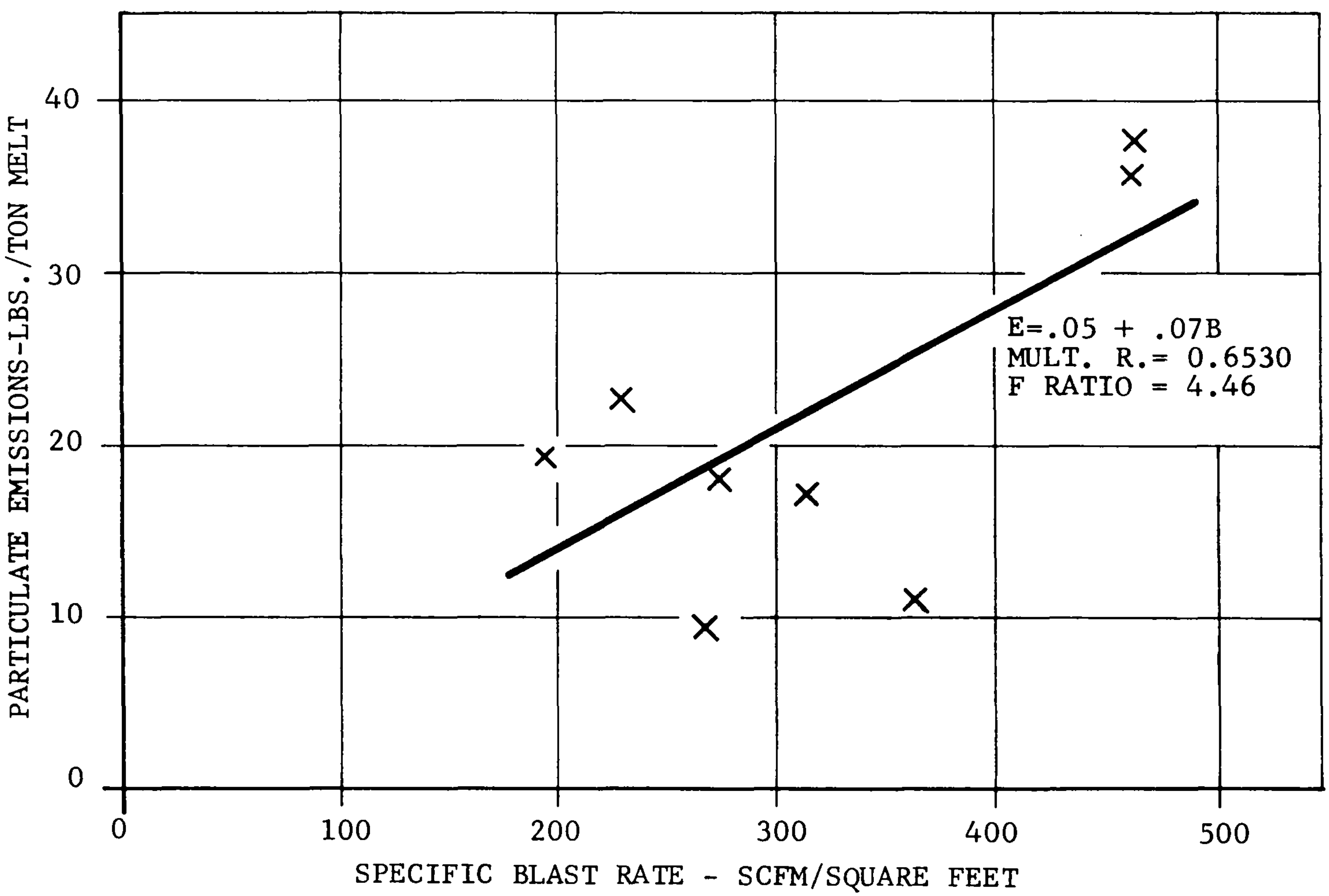


EXHIBIT IV-4

EFFECT OF SPECIFIC BLAST RATE AND COKE
RATE ON PARTICULATE EMISSIONS FROM UNLINED CUPOLAS

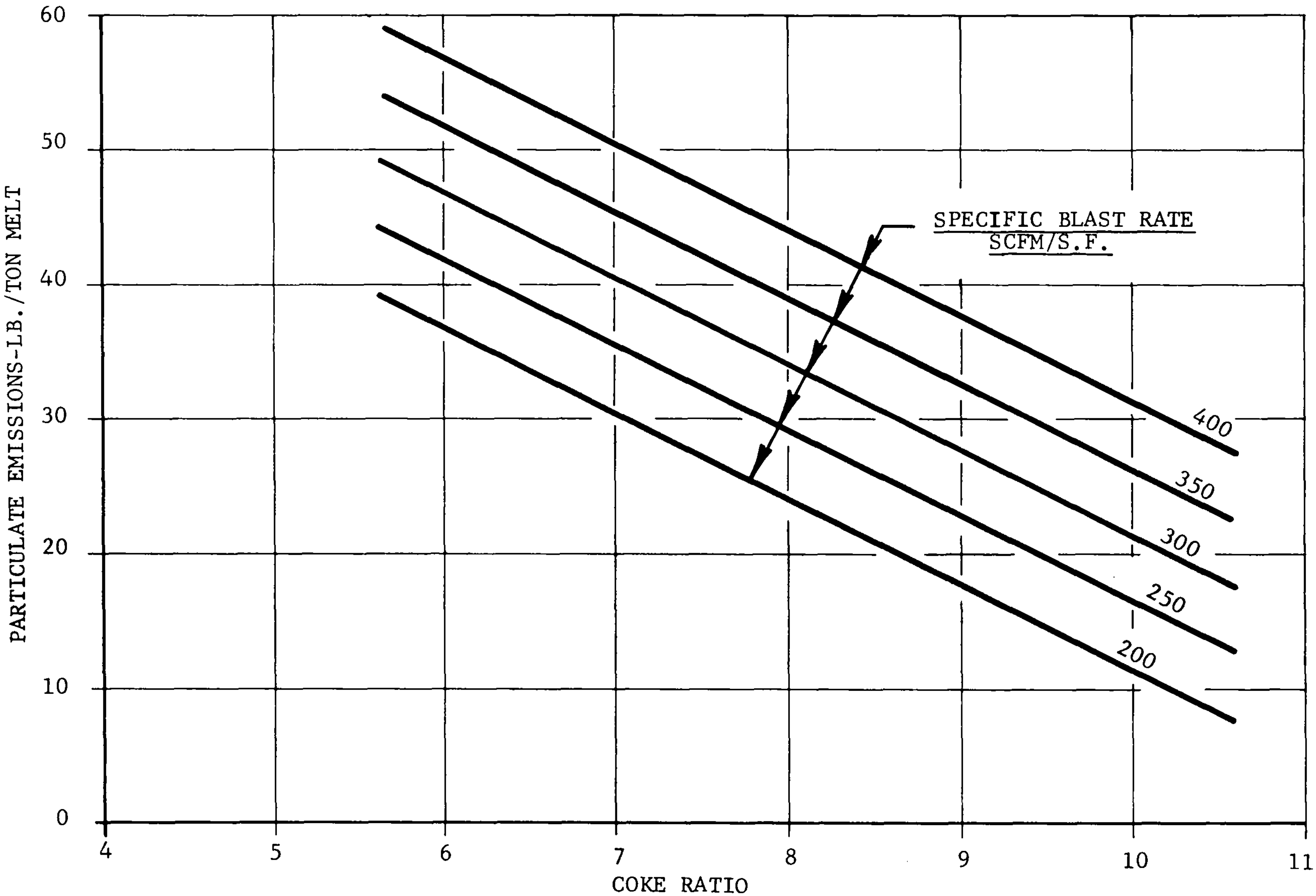


EXHIBIT IV-5

SIZE DISTRIBUTION FOR THREE ELECTRIC ARC INSTALLATIONS

Particle Size Distribution, Microns	Foundry A*	Foundry B	Foundry C
Less than 1	5%	8%	18%
Less than 2	15	54	61
Less than 5	28	80	84
Less than 10	41	89	91
Less than 15	55	93	94
Less than 20	68	96	96
Less than 50	98	99	99

Note: *Foundry A provided an agglomerated sample and is, therefore, less representative.

CHEMICAL ANALYSIS OF ELECTRIC ARC EMISSIONS

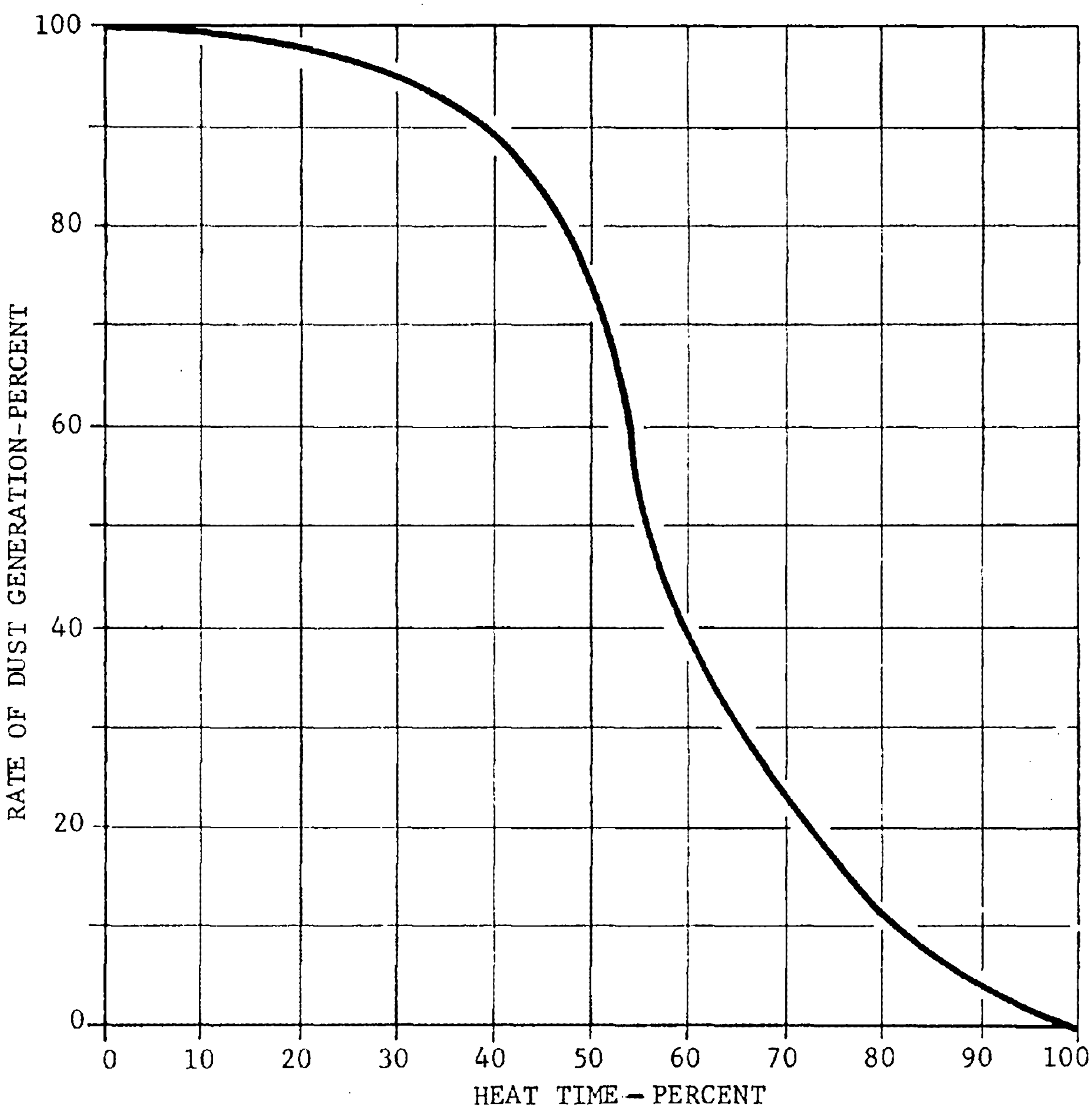
Oxides	Foundry A	Foundry B	Foundry C
Iron	75%-85%	75%-85%	75%-85%
Silicon	10	10	10
Magnesium	2	0.8	1
Manganese	2	2	2
Lead	1	2	0.5
Aluminum	0.5	1	0.5
Calcium	0.3	0.2	0.8
Zinc	0.2	2.	0.3
Copper	0.04	0.03	0.01
Lithium	0.03	0.03	0.03
Tin	0.03	0.3	0.02
Nickel	0.02	0.03	0.01
Chromium	0.02	0.07	0.02
Barium	0.02	0.07	0.01
Loss on Ignition	8.87	3.1	0
Ash	91.93	96.9	100

EMISSIONS DATA FROM ELECTRIC ARC MELTING FURNACES

Number	Furnace Shell Diameter Feet	Furnace Charge Tons	Furnace Cycle Hours	Emissions Produced Lb/Ton Charge
1	11.0	15	1.15	12.0(Est.)
2	12.0	20	1.5	6.0
3	8.0	5	1.0	20.0
4	12.0	20	2.5	18.3
5	7.0	3	1.75	10.0
6	12.0	25	4.0	4.0
7	8.0	5	1.0	40.0
8	7.0	3	1.75	12.7
9	7.0	2	2.0	10.7
10	7.0	2	1.3	13.4
11	7.0	3	2.0	5.3
12	9.0	6	2.3	15.3
13	9.0	6	2.0	12.8
14	11.0	18	3.0	6.1
15	9.0	6	1.2	29.4
16	9.0	6	1.75	12.7
17	8.0	4	2.0	11.0
18	11.0	14	1.75	7.5
19	12.0	19	1.7	15.0

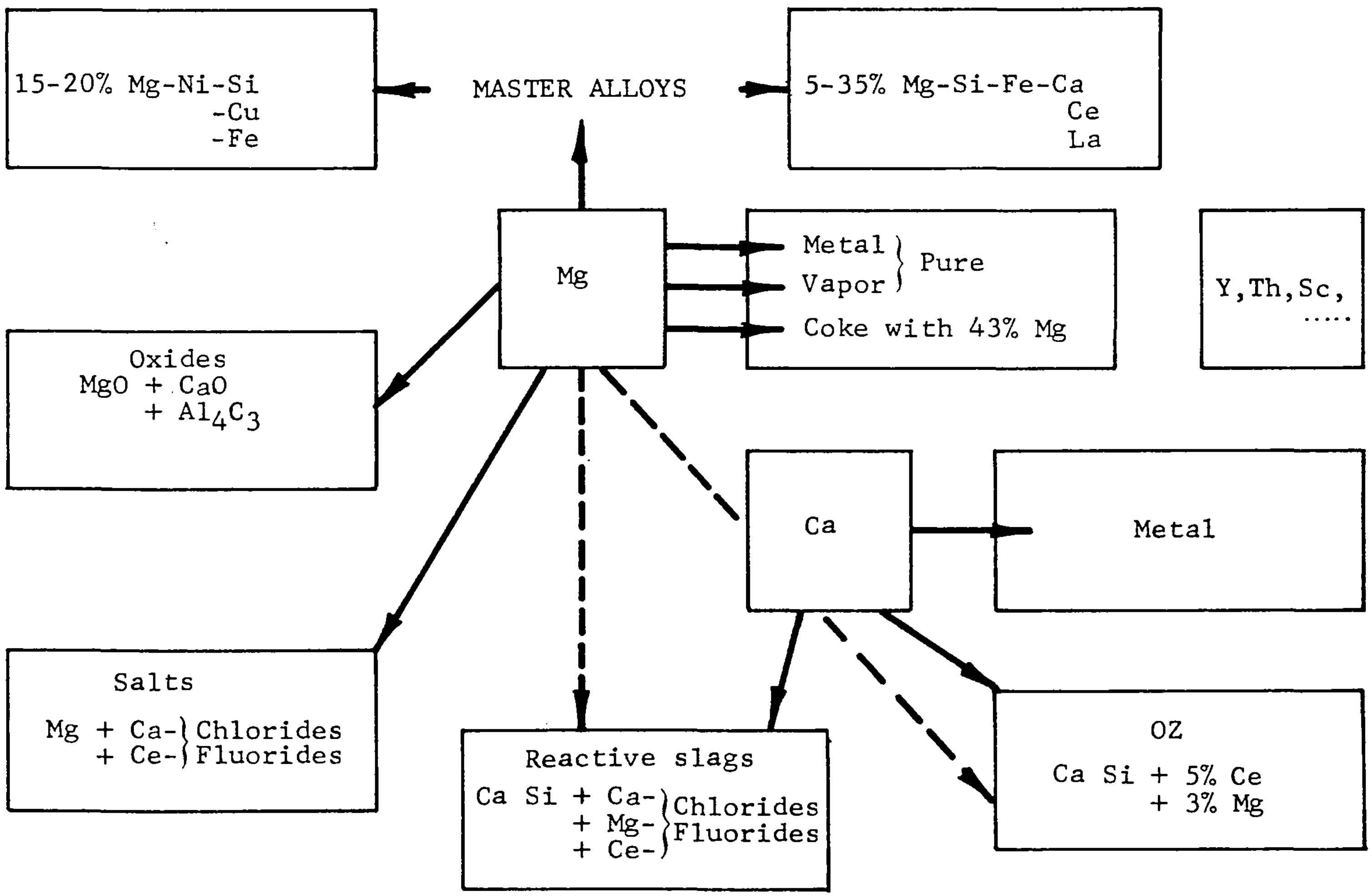
Sources:
- 1- 4 Foundry Visits
- 5- 9 AFS Foundry Air Pollution Manual
- 10-19 Los Angeles Air Pollution Manual

RELATIONSHIP BETWEEN RATE OF EMISSIONS AND HEAT CYCLE FOR ELECTRIC ARC MELTING



Source: Coulter, 1954, Los Angeles Air Pollution Manual.

TREATMENT AGENTS FOR PRODUCING DUCTILE IRON



Source: Modl, Comparing Processes for Making Ductile Iron, Foundry, July, 1970.

EXHIBIT IV-9

Molding Sand Gas Analyses

Sand Composition	A 4% Bentonite Oven Dried	B 4% Bentonite 2.5% H_2O	C 4% Bentonite 5% Water	D 4% Bentonite 1% Cereal Dried	E 4% Bentonite 1% Cereal 3.4% H_2O	F 1.5% Cereal Core Oil 1.0% Kerosene 1.0% Dried
CO_2	4.9	3.3	2.0	6.5	2.8	5.0
O_2	9.2	6.2	2.9	7.4	1.7	5.2
CO	2.4	6.3	11.3	10.8	11.5	30.4
H_2	0.9	33.0	46.1	2.5	50.3	25.6
Paraffins	0	1.2	0	0.4	2.9	2.2
N_2	82.6	49.7	37.7	72.4	30.8	31.6
Percent O_2 of O_2+N_2	15.7	20.2	21.7	21.0	25.0	44.5
CO/CO_2	0.49	1.91	5.7	1.66	4.10	6.08
Percent C	7.3	9.6	13.3	17.3	14.3	35.4

Sand Composition	G 4% Cereal 4% Bentonite 4% Water	H 4% Cereal 4% Bentonite Dry	I Oil Drag	J Oil Check	K Oil Cope	L Steel Cavity & Sprue
CO_2	2.5	2.3	6.4	6.4	6.8	5.0
O_2	3.0	6.2	4.3	5.5	8.9	9.4
CO	30.5	28.7	7.9	11.1	2.5	4.1
H_2	46.0	24.8	2.6	7.5	0.6	0.5
Paraffins	4.6	0.6	0.1	0	0	0.2
N_2	13.2	37.4	78.7	69.5	81.2	80.8
Percent O_2 of O_2+N_2	63.0	39.0	15.7	17.4	17.2	16.9
CO/CO_2	12.2	12.5	1.23	1.73	.37	0.82
Percent C	33.0	31.0	14.3	17.5	9.3	9.1

Source: "Nature of Mold Cavity Gases," Locke & Ashbrook, AFS Transactions, 1950.

EXHIBIT IV-10

MOLDING SAND
GAS EVOLUTION AND HOT PERMEABILITY

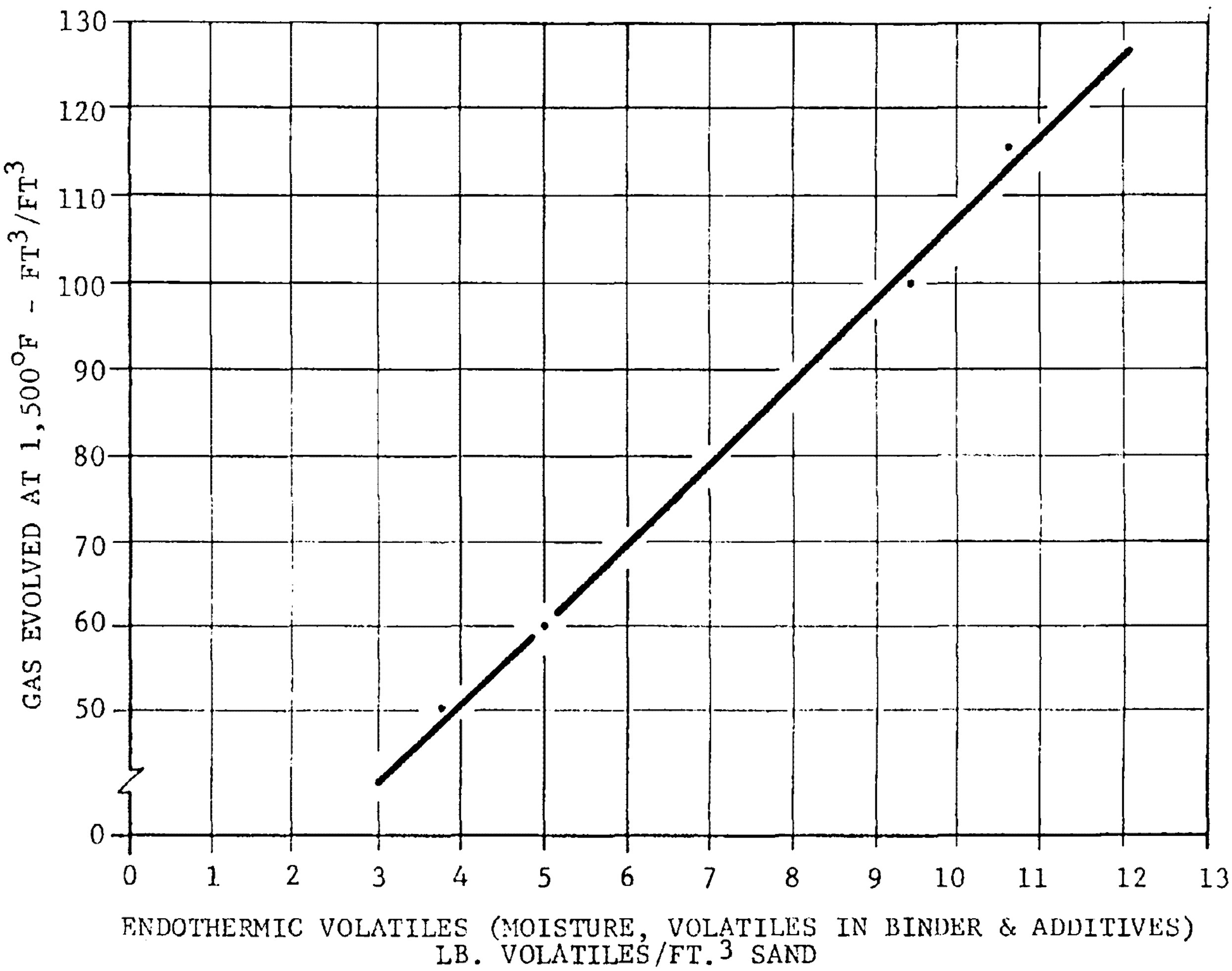
Bond Clay Added	Percent Tempering Water	CC Gas Evolved per Gram of Sand: Gas from Dried Specimen 1/2 Minute	3 Minutes	7 Minutes	Steam O 212° F.	Total Gas 212° F.	1,800° F.	Cubic Feet Gas at 1,800° F. per Cubic Foot of Sand
Washed and Dried Silica Sand plus Bond Clays								
5% Western Bentonite	2.5	.50	2.50	2.50	40.0	43.3	145.2	233.8
4% Southern Bentonite	2.5	3.50	3.50	3.50	41.5	46.1	154.9	247.8
11% Ohio fireclay	3.5	3.00	3.00	3.00	56.5	60.3	203.0	824.8
Silica Sand Bonded with 5 Percent Western Bentonite and Other Binders								
1-10 Sea Coal (Vol.)	3.0	9.00	19.50	19.75	49.8	76.2	256.0	409.6
1-35 Pitch (Vol.)	2.9	4.25	7.50	7.50	48.2	58.2	195.5	312.8
1% Cereal Binder	3.4	7.25	9.50	9.50	56.5	69.0	231.8	370.9
1% Resin Binder	3.4	5.25	7.00	7.00	56.5	65.4	219.7	351.5
1% Special Binder A	3.5	4.25	7.00	7.00	58.0	67.3	220.0	381.6
1% Special Binder B	2.0	2.25	3.75	3.75	33.2	87.7	126.7	202.7
1% Dextrine	3.5	8.00	8.75	8.75	58.0	69.6	234.0	74.4
Silica Sands Bonded with 5 Percent Western Bentonite and 1-10 Sea Coal Volume								
Washed and dried Ottawa	8.0	9.00	19.50	19.75	49.8	76.2	256.0	409.6
Western Michigan core sand	2.9	5.00	15.25	15.25	48.2	68.4	229.8	367.7
Michigan bank sand	2.8	10.25	25.00	25.50	46.5	80.3	270.0	432.0
Gas Evolution from Sands in Actual Use								
Steel foundry-old sand	2.0	4.50	5.25	5.25	33.2	40.1	134.7	215.5
Steel foundry-facing sand	3.1	12.25	13.25	13.25	51.4	69.1	232.0	371.2
Malleable foundry-system sand	3.7	9.75	18.00	18.25	61.5	85.5	288.0	460.8
Malleable foundry-facing sand	3.8	18.25	27.75	27.75	63.0	99.4	334.0	534.4
Gray iron foundry-system sand	3.8	11.25	28.75	33.00	63.0	106.5	358.0	572.8
Synthetic Sand vs. Naturally Bonded Sand								
95% Washed and dried Ottawa 5% Western Bentonite	2.5	.50	2.50	2.50	40.0	43.3	145.2	232.3
New Albany sand	4.8	9.00	11.00	11.00	78.0	93.3	314.0	502.4
New Ohio sand	7.8	11.00	15.25	15.25	124.8	145.0	480.5	778.3

Source: "Gas Developed in Molds," Dunbeck, Foundry, September, 1944.

EXHIBIT IV-11

EXHIBIT IV-12

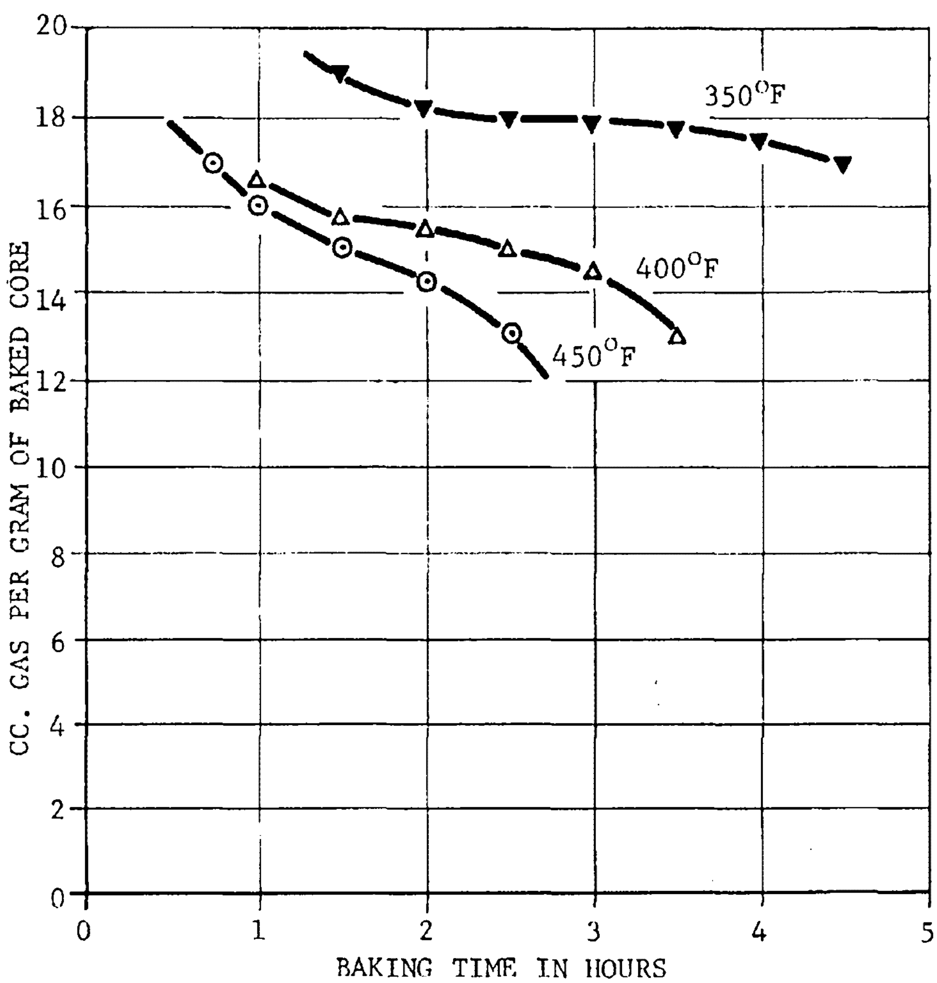
GAS VOLUME EVOLVED AS A
FUNCTION OF VOLATILES
CONTAINED IN MOLDING SAND



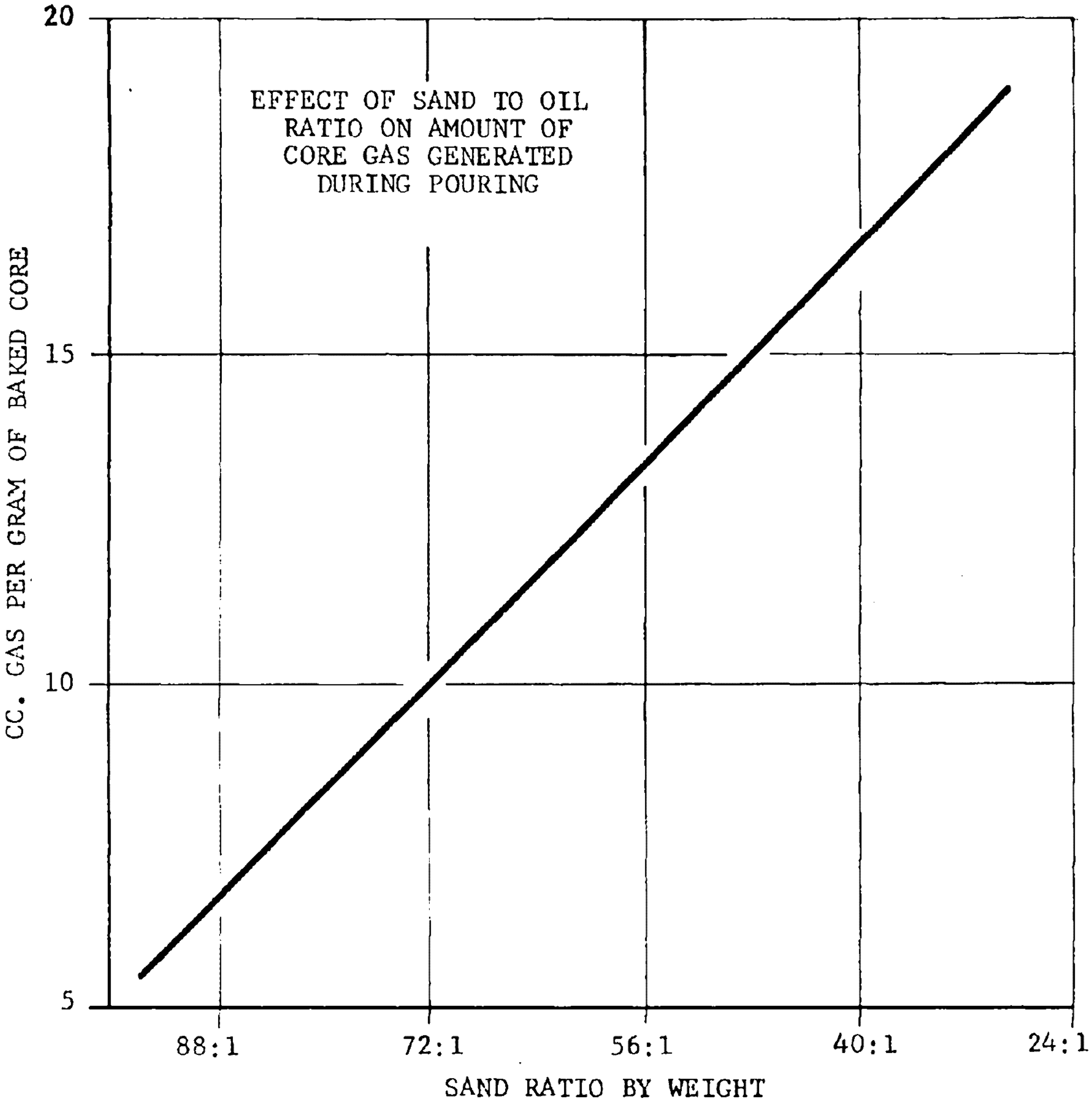
Note: Adapted from an article by F. Hoffman, "Property Changes and Conditioning of Repeatedly Circulating Foundry Sand Systems," Modern Casting, October, 1967.

EXHIBIT IV-13

EFFECT OF BAKING TIME ON
GAS GENERATED DURING POURING
FOR VARIOUS BAKING TEMPERATURES



Note: Adapted from Foundry Core Practice by H. Dietert, 1966, p. 172.



Source: Foundry Core Practice, H. Dietert, 1966.

INVENTORY OF IRON FOUNDRY EMISSIONS FROM MELTING OPERATIONS, 1969

Region	Castings Production Tons (1)	Molten Iron Production Tons (1)	Total Particulate Emissions Generated, Tons (3)	Carbon Monoxide Generated, Tons (3)	Particulate Emissions Emitted, Tons (4)	Carbon Monoxide Emitted, Tons (5)
New England Maine New Hampshire Vermont Massachusetts Rhode Island Connecticut	235,000	362,000	3,800	49,000	2,800	24,500
Middle Atlantic New York New Jersey Pennsylvania	3,501,000	5,143,000	51,000	594,000	38,000	297,000
East N. Central Ohio Indiana Illinois Michigan Wisconsin	8,225,000	12,613,000	126,000	1,541,000	94,500	770,500
West N. Central Minnesota Iowa Missouri Nebraska Kansas N. Dakota S. Dakota	607,000	881,000	9,100	115,000	6,800	57,500
South Atlantic Delaware Maryland Virginia W. Virginia N. Carolina S. Carolina Georgia Florida	473,000	662,000	6,800	88,000	5,100	44,000
East S. Central Kentucky Mississippi Alabama Tennessee	2,300,000	2,887,000	27,700	304,000	20,800	152,000
West S. Central Arkansas Louisiana Oklahoma Texas	531,000	748,000	7,700	100,000	5,800	50,000
Mountain Montana Colorado Arizona Nevada (2) Idaho New Mexico (2) Wyoming (2)	243,000	332,000	3,300	38,000	2,500	19,000
Pacific Washington Oregon California Hawaii Alaska	499,000	739,000	7,600	95,000	5,700	47,500
Total	16,614,000	24,367,000	243,000	2,924,000	182,000	1,462,000

Notes:
(1) Castings and molten iron production quantities from cupolas and electric arc furnaces only.

(2) No iron foundries are located in Nevada, New Mexico, and Wyoming.

(3) Particulate emissions and carbon monoxide generated are the estimated maximum produced.

(4) Particulate emissions emitted are estimated at 75% of maximum produced, with an average 25% being collected.

(5) Carbon monoxide emitted is estimated at 50% being burned and 50% released to the atmosphere.

INVENTORY OF IRON FOUNDRY EMISSIONS FROM NON-MELTING OPERATIONS, 1969

Region	Castings Production Tons	Molten Iron Production Tons	Total Particulate Emissions Generated Tons	Particulate Emissions Emitted Tons
New England	239,000	368,000	21,000	1,100
Maine				
New Hampshire				
Vermont				
Massachusetts				
Connecticut				
Middle Atlantic	3,643,000	5,603,000	319,400	16,200
New York				
New Jersey				
Pennsylvania				
East North Central	8,453,000	13,001,000	741,100	37,700
Ohio				
Indiana				
Illinois				
Michigan				
Wisconsin				
West North Central	677,000	1,041,000	59,300	3,000
Minnesota				
Iowa				
Missouri				
Nebraska				
North Dakota				
South Dakota				
South Atlantic	485,000	746,000	42,500	2,200
Delaware				
Maryland				
Virginia				
West Virginia				
North Carolina				
South Carolina				
Georgia				
Florida				
East South Central	2,327,000	3,579,000	204,000	10,400
Kentucky				
Mississippi				
Alabama				
Tennessee				
West South Central	551,000	847,000	48,300	2,500
Arkansas				
Louisiana				
Oklahoma				
Texas				
Mountain	249,000	383,000	21,800	1,100
Montana				
Colorado				
Arizona				
Nevada (1)				
Idaho				
New Mexico (1)				
Wyoming (1)				
Pacific	531,000	817,000	46,600	2,400
Washington				
Oregon				
California				
Hawaii				
Alaska				
Total	17,155,000	26,385,000	1,504,000	76,600

Note: (1) No iron foundries are located in Nevada, New Mexico, and Wyoming.

SAMPLING AND ANALYTICAL TECHNIQUES

INTRODUCTION

Sampling and analytical techniques for the determination of emission rates from industrial processes have been standardized for many specific particulate and gaseous materials. The techniques described in the following paragraphs are those most widely used in the testing of iron foundry emissions testing. The format and wording for most procedures correspond to the source indicated for each procedure.

SAMPLING TECHNIQUE

Scope

The primary objective of stack testing is to determine the nature and/or quantity of emissions being released into the atmosphere. Sampling procedures that follow are applicable to the cleaned gas side of the control unit.

Apparatus

The accuracy of emission testing results is dependent upon qualified personnel conducting the test and the use of the proper apparatus for the material to be collected. Figure 1 illustrates information on sampling locations and apparatus most commonly involved in stack testing.

Sampling Principles

The location and number of sampling points are based on size and shape of the duct, uniformity of gas flow in the duct, availability of an adequate sampling port, and the space required to set up the equipment. Unfortunately, ideal conditions are seldom found in field testing and agreement on these factors must be reached before conducting the test.

To insure constancy of test conditions and results, complete information must be developed as to continuous or cyclic operation; nature, weight and composition of materials; gas volume and fluctuations; pressure; temperature and humidity; presence of other devices such as afterburners; and related conditions affecting the operation and equipment. These factors will regulate the time, number and duration of test runs.

Stack Gas Velocity

To determine particulate concentration in an exhaust stack, isokinetic source sampling must be used. This is the condition that exists when the velocity in the nozzle of the sampling tube is exactly the same as that in the stack. Isokinetic sampling is not mandatory when only gaseous substances are to be assayed.

In isokinetic sampling, the traverse area of the duct must be divided into equal areas and a pitot traverse taken. The use of the S-type pitot is recommended where particulates are involved to avoid any possibility of partial plugging and faulty readings. The velocity at each point must be calculated, and the volume of flow required to maintain that velocity in the sampling tip should volume fluctuate. Provisions must be made so that the volume can be recalculated immediately each time the pressure changes at the meter. However, when sampling is downstream from a gas cleaner, the volume is controlled by the system's fan and remains relatively constant and this procedure may not be necessary.

Detailed procedures on conducting velocity measurements are given in Bulletin WP-50 of the Western Precipitation Company, ASME Performance Test Code 27-1957 and the Industrial Ventilation Manual of the American Conference of Governmental Industrial Hygienists.

Concurrent with conducting the pitot traverse, it is essential to determine the temperature of the stack gas. The measuring device will be dependent on the temperatures involved.

Sample Probe

In assembling the sampling probe, teflon tape should always be used instead of pipe dope to prevent adherences of particulates. Long radius bends should be used instead of elbows to facilitate cleaning. The probe should be just long enough for the task at hand. The rest of the train should be assembled and tested for leaks.

Temperature and Humidity

If the gas sampled is hot and humid, condensation may occur in the probe or in the filter holder. The probe or filter holder must be heated to stop condensation from occurring because the water formed will trap water on the walls of the apparatus and will interfere with the filtration of particulates. Temperature control baths may be required for gas absorbers. In some cases the probe can be provided with a water cooling jacket.

Condensation

A condenser in the sampling train is required if the gas is humid. This serves two purposes. First, it removes excess water which may condense and damage the gas meter. Second, and of vital importance, a condenser gives assurance that the gas passing through the train is saturated at an identifiable point. This provides the basis for exact calculations of the volume of dried gas metered and conversion to standard conditions.

Collection Devices

The characteristics of the material in the stack will determine the collection method required. Dry filter mediums, of a variety of types, are most commonly used for particulate matter. Although in some cases the wet impingement method followed by a thimble is used. Gases are collected in absorbers with a proper absorbing solution. Grab sample units are available for spot sampling.

Flow Meters

If a dry gas meter is used, it must be calibrated before each use. If an orifice meter, or flow-type meter, is used it must also be calibrated each time, and it must have enough sensitivity so that readings can be obtained to less than one percent. Finally, if volume is obtained by multiplying an instantaneous reading by the time of the operation, fluctuations must be kept to one percent.

Vacuum Source

A vacuum source is required to draw the sample from the stack through the sampling train. A variety of pumps or ejectors are available for this purpose. Their capacity must be sufficient to draw the gas through the sample train at the required volume. The range is from one liter to several cubic feet per minute.

Sampling time will be dependent upon the factor of obtaining a representative sample of the operation. It may vary from several long continuous integrated samples of 30 to 60 minutes or a number of short samples of 5-10 minutes.

ANALYTICAL PROCEDURES

Introduction

Analytical procedures for a number of materials are given in the sections that follow. All calculations must be according to standard procedures and the standard conditions of temperature at 70 degrees Fahrenheit and an atmospheric pressure of 29.92 inches of mercury.

Particulate Matter

(a) Scope

The definition of particulate matter accepted by the dust collection industry is given in the ASME Performance Test Codes 21-1941 and 27-1957. In essence, this defines particulate matter as all filterable solids present at standard temperature in an effluent gas stream.

(b) Auxiliary Apparatus

- Filter Media - Efficiency of collection must be at least 99% for all particulates encountered and must be resistant to both heat and moisture.
- Balance - Macro analytical balance or equivalent.
- Drying Oven - Suitable for drying filters for about 5 hours at 105° C.
- Desiccation - To retain dried filters before weighing.

(c) Sampling Procedure

The first step in sampling is to prepare the filtering medium. An identification number should be provided for each filter and recorded on a separate data sheet. Prior to weighing, the filter should be dried for about 5 hours at about 105° C and then weighed immediately. This weight should be recorded on the data sheets and not on the filter. In order to keep weighing errors at a minimum, careful handling of the filters is required.

Preferably the pitot traverse, temperature and humidity readings should be taken not more than one-half hour before sampling is begun. Assemble the sampling train as shown in Figure 1 and proceed with the sampling by inserting the probe into the test stack. Continual observation of the sampling train during the entire sampling period is required to record any changes in pressure, temperature and airflow. This information, along with barometric pressure, sampling time and rate, is recorded on the sampling data sheet. Complete information on the process should also be noted on the sampling data sheet.

Length of the sampling time, at any specific point in the stack, will be contingent upon changes, if any, in the process or fluctuations of air volume. The sampling time should at least cover a complete cycle and will vary from 30-60 minutes. If airflow is not uniform in the stack, 5- to 10- minute samples at each of the traverse points should be obtained. Samples taken during start-up and burn-down periods should, as a rule, be considered separately from those taken during the production cycle of the cupola.

After a run is completed the probe must be cleaned of retained particulate matter. An acceptable procedure is to brush with a long flexible brush while the sample train is pulling in clean air. For other contaminants, follow procedures, if any, indicated for the specific material.

(d) Sample Preparation

Collected samples should be dried and placed in a desiccator to reach equilibrium before weighing. The difference between the original weight and final weight is the total amount of particulate matter collected.

(e) Calculations

The total particulate matter collected is expressed in grams. From this value, calculations can be made to express the findings in grains/SCF, pounds/hour, or pounds/1,000 pounds of gas, using the following constants:

One (1) gram = 15.43 grains
One (1) pound = 7,000 grains
One (1) gram = 0.002205 pounds
One (1) standard cubic foot of air = 0.075 pounds

1. Grains/SCF

$$\text{Grains/SCF} = \frac{(\text{Grams})\ (15.43)}{\text{Total SCF sampled}}$$

2. Pounds/Hour

$$\text{Pounds/hour} = \frac{60\ (\text{grains/SCF})\ (\text{total gas volume to atmosphere - SCFM})}{7{,}000}$$

3. Pounds/1,000 Pounds Gas

$$\text{Pounds/1,000 Pounds gas} = \frac{(\text{grams})\ (2.205)}{(0.075)\ (\text{total SCF sampled})}$$

Arsenic

Source: American Conference of Governmental Industrial Hygienists.

(a) Scope

Stack sampling for arsenic is based on the reaction of arsine with silver diethyldithiocarbamate. The amount of arsenic, in the air sample, is read directly from the calibration curve.

(b) Auxiliary Apparatus

- Greenberg-Smith Impinger.
- Beckman DU Spectrophotometer with photomultiplier or equivalent
- Arsine Generator (See Figure 2)

(c) Reagents

Silver Diethyldithiocarbamate - a cooled solution of silver nitrate (1.7 g in 100 ml distilled water) is added to a cooled solution of sodium diethyldithiocarbamate (2.25 g in 100 ml distilled water). The lemon yellow precipitate is filtered off, washed thoroughly with distilled water and dried in a vacuum desiccator below 20^{o} C.

Pyridine - Mallinckrodt reagent grade pyridine is passed through an alumina column 1 inch in diameter and 6 inches in depth, at the rate of approximately 150 ml per hour. This process may remove a considerable quantity of colored material.

Arsine Absorbing Solution - Dissolve 1 g of silver diethyldithiocarbamate in 200 ml of chromatographed pyridine and filter the solution.

Hydrochloric acid - Baker's analyzed, specific gravity 1.19.

Potassium Iodide Solution - Dissolve 15 g reagent grade potassium iodide in 100 ml distilled water.

Stannous Chloride Solution - Dissolve 40 g stannous chloride dihydrate in 100 ml hydrochloric acid.

Zinc - Baker's analyzed; granular 20 mesh.

Lead Acetate - Dissolve 10 g reagent grade lead acetate in 100 ml distilled water.

Arsenic Standard Stock Solution - Dissolve 1.320 g arsenic trioxide in 10 ml of 40% sodium hydroxide and diluted to 1 liter with distilled water. (Various strengths of standard solutions are prepared by further diluting this stock solution with suitable volumes of water, triple distilled in glass.)

Nonag - Stopcock grease, Fischer Scientific Co.

(d) Sampling Procedure

Assemble sampling train of probe, impinger with 100 ml of distilled water, flow meter and vacuum pump. Sampling rate is at 1 CFM for a period long enough to provide a minimum of 30 cubic feet at standard conditions.

(e) Analytical Procedure

Calibration curve - known microgram amounts of arsenic (1-15 micrograms) in the form of standard arsenic solution are pipetted into 125 ml Erlenmeyer flasks. Distilled water is added to make the total volume 35 ml. To the flasks are added 5 ml hydrochloric acid, 2 ml 15% potassium iodide solution, and 8 drops of stannous chloride solution. The flasks are swirled and allowed to stand for 15 minutes.

Three ml of the pyridine solution of silver diethyldithiocarbamate are placed in the absorbing tube, which is attached to the scrubber containing glass wool impregnated with lead acetate. (See Figure 2.)

The ground joints are lubricated with "Nonag" stopcock grease, 3 g of granulated zinc are added to the solution in the flask, and the receiving tube is inserted immediately. Arsine evolution is completed in about 30 minutes.

At the end of this time, the absorbing solution is transferred to a 1 cm square cell and the absorbance measured at 560 millimicrons in the Beckman spectrophotometer. Plotting measured absorbances against micrograms of arsenic taken produces the standard curve.

Air samples, after the previously described preparation treatment, are treated in the same manner as the standards.

(f) Calculations

Arsenic, in the form of arsine, displaces an equivalent amount of silver from silver diethyldithiocarbamate..

$$\text{mg As/M}^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

Where
v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Beryllium

Source: Michigan Department of Public Health.

(a) Scope

This method describes a procedure for determining beryllium in stack gases.

(b) Auxiliary Apparatus

- Millipore filters and holder.
- Bausch & Lomb Large Littrow Emission Spectrograph or equivalent.

(c) Reagents

Platinum Internal Stock Solution - Purchase directly from Jarrell-Ash Company a 10% platinic chloride solution. This calculates out to be 57.88 mg platinum in 1 ml solution.

Platinum Internal Standard Working Solution - Pipette 1 ml of platinum stock solution containing 57.88 mg Pt per ml into a

25 ml volumetric flask, take to volume with water giving a solution containing 116 micrograms platinum/.05 ml.

Standard Beryllium Solutions:

1. Beryllium stock solution. Dissolve .0982 g of $BeSO_4 \cdot 4H_2O$ in 10 ml of redistilled 1:1 hydrochloric acid and dilute to 100 ml with distilled water. Solution contains 5.0 mg beryllium per 100 ml or 2.5 micrograms Be/.05 ml.

2. Working beryllium standard solutions. These should be prepared from the stock solution just before use. Suggested concentrations are from .003 to .5 microgram Be/.05 ml.

Nitric Acid - To clean all laboratory glassware.

(d) Sampling Procedure

Assemble sampling train of probe, millipore filter and holder, flow meter and vacuum pump. Sampling rate at 1 CFM for a period long enough to provide a minimum of 10 CF at standard conditions.

(e) Analytical Procedure

The millipore filter containing the sample is transferred to a chemically clean 125 ml beaker. The filter and sample are wet ashed with nitric acid. The residue is then dissolved in 3 ml of concentrated nitric acid and 1-2 ml of distilled water. Transfer to a graduated centrifuge tube, rinse the beaker with water and add the rinsing to the sample solution. Evaporate to a volume of 0.2 ml and if an appreciable amount of salt is present, a volume of more than 0.2 ml may be required.

The standard curve is plotted on log-log paper and micrograms Be per .05 ml is plotted versus the intensity ratio of Be 2348.6 line over Pt 2357.1 line. The standard curve is usually set up in the range of .003 microgram Be/.05 ml to .5 microgram Be/.05 ml. Six beryllium concentrations used to establish the working curve are prepared as follows:

For the first 3 concentrations, the stock solution containing 50 micrograms Be/ml is diluted 1 ml to 100 in distilled water giving a working solution of .5 microgram Be/ml.

1. .003 microgram Be/.05 ml. Pipette 1.2 ml of working standard beryllium solution (.5 microgram Be/ml) into a 10 ml volumetric flask and take to volume with water.

2. .005 microgram Be/.05 ml. Pipette 2 ml of working standard beryllium solution (.5 microgram Be/ml) into a 10 ml volumetric flask and take to volume with water.

3. .01 microgram Be/.05 ml. Pipette 4 ml of working standard beryllium solution (.5 microgram Be/ml) into a 10 ml volumetric flask and take to volume with water.

4. .05 microgram Be/.05 ml. Pipette .2 ml of stock beryllium solution (50 micrograms Be/ml) into a 10 ml volumetric flask and take to volume with water.

5. .1 microgram Be/.05 ml. Pipette .4 ml of stock beryllium solution (50 micrograms Be/ml) into a 10 ml volumetric flask and take to volume with water.

6. .5 microgram Be/.05 ml. Pipette 2 ml of stock beryllium solution (50 micrograms Be/ml) into a 10 ml volumetric flask and take to volume with water.

Spectrographic apparatus, materials and exposure conditions are as follows:

1. Optical conditions - 10 micron slit is used in the spectrograph.

2. Densitometer - Non-recording National Spectrograph Spec Reader.

3. Electrodes - Upper Electrode (cathode) United Carbon Products Company, 3/16" diameter, sharpened to a point in a regular de-leaded pencil sharpener. Lower Electrode (anode). United Carbon Products Electrode, catalog No. 100-L, 1/4" diameter, crater is 3/16" diameter and 5/32" deep.

4. Exposure conditions - 220 volts DC arc, operating at 7.5 amperes with a constant gap of 5 mm maintained between the anode and cathode, exposure time is until burn-out of lithium chloride buffer.

5. Photographic - Eastman Kodak Spectrum Analysis No. 1 Plate, developed 3.5 minutes in Eastman D-19 Developer at 68° F and fixed for 8 minutes in Eastman Koda Fixer (National Spectrographic Developing machine). Emulsion is calibrated by use of the two-step filter in front of the slit. The density of

the filter section is given by Bausch and Lomb Company, makers of the filter.

6. Nitrogen - AirCo dry nitrogen, flow rate regulated by F. W. Dwyer Manufacturing Company flow meter, maximum flow rate 6 liters per minute, regulator 3,000 pounds. The nitrogen flow around the electrode is between 3-4 liters per minute.

Preparation of the electrodes for both standard curve and sample analysis is as follows: A 1/4" diameter electrode is waterproofed by immersion in Dow Corning silicone solution (2% in acetone), and air dried for at least 30 minutes. A 10 mg charge of lithium chloride-graphite buffer is placed in the electrode and packed by tapping gently on the table top.

Into the electrodes prepared as described above is pipetted .05 ml of the platinum internal standard working solution (116 micrograms/.05 ml). The electrodes are placed in a 60° C oven and allowed to dry. Upon removal from the oven, .05 ml of the standard beryllium solution is pipetted into the appropriate electrodes. From the centrifuge tubes, where the samples have been evaporated down, is pipetted .05 ml into the appropriate electrodes. The electrodes are then returned to the 60° C oven and maintained at that temperature until dry. The temperature is then brought up to 105° C and maintained at that temperature for 1 hour. The electrodes are now removed from the oven and are ready for analysis. After the spectrograph and power supply have been set as previously described, the electrodes are placed in the respective electrode holders. The nitrogen flow is turned on and set at a rate of between 3-4 liters per minute around the lower electrode. With the shutter open during the entire exposure the arc is lit and allowed to run until burn-out of the lithium chloride buffer which is indicated by a vanishing of the red lithium color.

After the plate has been developed and dried as described previously, it is placed on the densitometer and the percent transmission set to 100 on a clear portion of the plate. The percent transmittance value of Be 2348.6 and the background adjacent to this line is read. The percent transmittance value of Pt 2357.1 line is also read. Through the use of the gamma curve the percent transmission values of the bismuth line and the background adjacent to it and the Pt line are transformed to I values and a ratio taken of I value Be 2348.6 over I value Pt 2357.1 made. Each one of the varying concentrations of beryllium standard curve and of the sample is run in triplicate and an average of these taken for the final calculation. The amount of beryllium per .05 ml sample is read from the standard curve.

(f) Calculation

$$\text{micrograms Be/M}^3 = \frac{V \cdot Y}{v \cdot Va}$$

where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Cadmium

Source: Michigan Department of Public Health.

(a) Scope

Stack testing for cadmium can be accomplished by the polarograph method using a dropping-mercury electrode with the sample as the electrolyte.

(b) Auxiliary Apparatus

Sargent Polarograph - Model XX1, recording type or equivalent.

(c) Reagents

Standard Lead Solution - Dissolve approximately 25 grams of C.P. $Pb(NO_3)_2$ in minimum of hot water and cool with stirring. Filter with suction on small Buchner funnel. Repeat recrystallization. Dry crystals at 100^o-110^o C to constant weight, cool in desiccator and store in tightly stoppered pyrex bottle. The product has no water of crystallization and is not appreciably hygroscopic. Weigh exactly 0.1599 grams of recrystallized C.P. $Pb(NO_3)_2$, put into 500-ml volumetric flask, and take to volume with 0.1 N HCl. This gives a standard lead solution containing 200 micrograms Pb/ml with 0.1 N HCl as the electrolyte. The 0.1 N HCl should be prepared from constant boiling hydrochloric acid.

Standard Cadmium Solution - Weigh exactly 0.2744 grams of $Cd(NO_3)_2 \cdot 4H_2O$ into a 500-ml volumetric flask and take to volume with 0.1 N HCl. This gives a standard cadmium solution containing 200 micrograms cadmium per ml with 0.1 NHCl as the electrolyte. As in the lead solution the 0.1 N HCl should be prepared from constant boiling hydrochloric acid.

Oxygen Absorbent for Purification of Nitrogen - Pass nitrogen through a first scrubbing flask (a midget impinger) containing concentrated NH_4OH and copper turnings. Caution: Make certain hole in impinger is not plugged before turning nitrogen under pressure on. Then pass nitrogen through a second scrubbing flask containing concentrated sulfuric acid, again making certain this is not plugged before applying pressure.

0.2 N hydrochloric acid - Prepare this from constant boiling hydrochloric acid according to outline in Lange's Handbook.

Clean, Dry Mercury - Purchase from Eberback & Son

(d) Sampling Procedure

Assemble sampling train of probe, impinger with 100 ml of 5% nitric acrid, flow meter and vacuum pump. Sample at rate of 1 CFM for a period long enough to provide a minimum of 30 cubic feet at standard conditions.

(e) Analytical Procedure

Sample Preparation - Transfer the collecting solution from the impinger into a 250 ml beaker, wash out impinger with hot 5% nitric acid and all taken down to dryness on a hot plate. Cool and add 25 ml of 0.2 N HCl. Heat just to boiling and transfer to a 50 ml volumetric flask. Dilute to volume with distilled water which will dilute the 0.2 N HCl to 0.1 N HCl which is the electrolyte.

Transfer a 10-ml aliquot from the 50-ml volumetric flask into the polarographic cell, add 1 ml of 200 micrograms Pb per ml solution, and remove oxygen from the cell by bubbling nitrogen, which is being purified as described under reagents, through for three to five minutes. The initial voltmeter is set at .3 volts, the span voltmeter is set at .6 volts, thereby giving a range from -.3 volts to -.9 volts. This is sufficient as lead "comes off" at approximately -.44 volts and cadmium at approximately -.66 volts. The sensitivity setting might have to be found by trial and error; 0.020 suffices for most samples although if the cadmium is low the sensitivity will have to be increased (decreasing the number of microamperes/mm.).

If there is a possibility that Pb is present in the sample an aliquot of the sample should be run in the polarographic cell first, without any internal standard added. If there is Pb present in the sample, this must be taken into account when Pb, the internal standard, is added.

Standard Curve - Into the polarographic cell is introduced 1 ml of 200 micrograms Pb per ml solution, 1 ml of 200 micrograms Cd per ml solution and 9 ml of 0.1 N HCl. This gives a total amount of solution in the cell of 11 ml, thereby enabling a later removal of 10 ml of the sample and 1 ml of 200 micrograms Pb per ml internal standard solution. Also, there is an electrolyte in the cell of 0.1 N HCl. Both the volume of liquid in the cell and the electrolyte for standard curve and sample are critical for a proper analysis.

On the standard curve the heights of the Pb and Cd curves are measured in mm. The Cd to Pb ratio is found, which is divided by the number of micrograms of Cd used giving a factor for 1 microgram Cd versus 200 micrograms Pb. It is suggested that 200 micrograms Pb be used as an internal standard in each sample for Cd thereby simplifying the calculations. The factor for 1 microgram Cd versus 200 microgram Pb, found at the beginning of the series of samples being analyzed, will be used for the calculations throughout this series.

(e) Calculations

For the sample "polarogram" the heights of the Pb and Cd curves are measured in mm. and the Cd to Pb ratio found in the same manner as the standard curve. The ratio found here is divided by the factor found in the standard curve for 1 microgram Cd versus 200 micrograms Pb giving the number of micrograms of Cd in the aliquot put into the polarographic cell.

$$mg\ Cd/M^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

Where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Fluoride

Source: Talvitie method modified by Michigan Department of Public Health.

(a) Scope

This method describes a procedure for determining fluoride in stack gases.

(b) Auxiliary Apparatus

- Standard impinger with fritted glass bubbler.
- 250 ml Claissen flasks.
- 100 ml Nessler Tubes.

(c) Reagents

Standard Sodium Fluoride - Make a solution containing 1 mg of fluoride per ml (2.21 g of sodium fluoride to 1 liter). Take 10 mls of this solution and dilute to 1 liter; 1 ml of this dilution contains .01 mg fluoride.

Color Forming Reagent - Dissolve 36.99 g of sodium sulfate in about 500 ml of hot distilled water and 17.7 g of sodium formate in about 200 ml of hot distilled water. Mix together and when cooled, add 0.1436 g thorium nitrate tetrahydrate and 11 ml of 90% formic acid.

Alizarin monosodium sulfonate indicator 128.25 mg dissolved in 1 liter of distilled water.

Nitric Acid - About 5 ml concentrated acid, diluted to a liter with distilled water.

Sodium Hydroxide - .5 N. (20 g dissolved in 1 liter of water).

Silver Sulfate.

Concentrated Sulfuric Acid.

(e) Sampling Procedure

Assemble sampling train of probe, impinger with fritted glass bubbler containing 100 ml of a 2% sodium hydroxide solution, flow meter and vacuum pump. Sample at a rate of 1 CFM for a period long enough to provide a minimum of 15 cubic feet at standard conditions.

(f) Analytical Procedure

Sample Preparation - Transfer the collecting solution from the impinger into a Claissen flask. Slowly add 35 ml of concentrated sulfuric acid (using small long stem funnel) to content, submerging and swirling flask in cool-cold water while adding the acid--this offsets the loss of HF. Add boiling chips and silver sulfate (to cover the end of a spatula). Close the flask with a two-hole rubber stopper, through which passes a thermometer and a 6 mm O.D. glass tube drawn to capillary size and extends down into the solution. Connect tube to a separatory funnel containing water. This is to slowly add water to both cool the flask and to replenish the water boiled off due to distillation in the Claissen flask.

The distillation flask should be placed on a pad of transite or asbestos, or on a plate of aluminum with a hole about 2 inches in diameter made to fit the flask perfectly.

Regulate the heat under the steam distillation flask so that the distillate being collected remains cool. Adjust the application of heat to the still so that a temperature of 165^{o} C is maintained. Collect the distillate in a 250-ml volumetric flask or in a 250-ml beaker, and then make up to exactly 250 ml in a volumetric flask. Stopper the flask and mix. Pipette 25 ml into a 100-ml-long form Nessler tube. Add 5.0 ml of alizarin indicator. Titrate carefully with a .5 N sodium hydroxide until the solution changes from yellow to a decided pink. Back titrate with the dilute nitric acid until the solution changes to a pure yellow. Dilute to about 90 ml, add 3 ml of thorium reagent, make up to exactly 100 ml and mix well. After 30 minutes, compare with the standards. If the same is beyond the range of the standards, use a smaller aliquot. If it is too close to the standard containing no fluorine, double or treble the aliquot.

A blank must be carried through all the steps of the procedure, using the same amounts of reagents as are used in the samples. An aliquot of 75 ml is usually necessary to determine the amount of fluorine present in the blank.

(f) Calculations

Calculate the total amount of fluorine present in the blank and subtract this from the total fluorine found in each sample.

$$\text{mg F/M}^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Lead

Source: Michigan Department of Public Health.

(a) Scope

Stack testing for cadmium can be accomplished by the polarograph method using a dropping-mercury electrode with the sample as the electrolyte.

(b) Auxiliary Apparatus

Sargent Polarograph - Model XXl, recording type, or equivalent.

(c) Reagents

Standard Lead Solution - Dissolve approximately 25 grams of C.P. $Pb(NO_3)_2$ in minimum of hot water and cool with stirring. Filter with suction on small Buchner funnel. Repeat recrystallization. Dry crystals at 100°-110° C to constant weight, cool in desiccator and store in tightly stoppered pyrex bottle. The product has no water of crystallization and is not appreciably hygroscopic. Weight exactly 0.1599 grams of recrystallized C.P. $Pb(NO_3)_2$, put into 500-ml volumetric flask, and take to volume with 0.1 N HCl. This gives a standard lead solution containing 200 micrograms Pb/ml with 0.1 N HCl as the electrolyte. The 0.1 N HCl should be prepared from constant boiling hydrochloric acid.

Standard Cadmium Solution - Weight exactly 0.2744 grams of $Cd(NO_3)_2 \cdot 4H_2O$ into a 500-ml volumetric flask and take to volume with 0.1 N HCl. This gives a standard cadmium solution containing 200 micrograms cadmium per ml with 0.1 N HCl as the electrolyte. As in the lead solution, the 0.1 N HCl should be prepared from constant boiling hydrochloric acid.

Oxygen Absorbent for Purification of Nitrogen - Pass nitrogen through a first scrubbing flask (a midget impinger) containing concentrated NH_4OH and copper turnings. Caution: Make certain hole in impinger is not plugged before turning nitrogen under pressure on. Then pass nitrogen through a second scrubbing flask containing concentrated sulfuric acid, again making certain this is not plugged before applying pressure.

0.2 N. Hydrochloric Acid - Prepare this from constant boiling hydrochloric acid according to outline in Lange's Handbook.

Clean, Dry Mercury - Purchase from Eberbach and Son.

(d) Sampling Procedure

Assemble sampling train of probe, impinger with 100 ml 5% nitric acid solution, flow meter and vacuum pump. Sample at rate of 1 CFM for a period long enough to provide a minimum of 30 cubic feet at standard conditions.

(e) Analytical Procedure

Sample Preparation - Transfer the collecting solution to a 250-ml beaker, wash out impinger with 5% hot nitric acid and all taken down to dryness on a hot plate. Cool and add 25 ml of 0.2 N HCl. Heat just to boiling and transfer to a 50-ml volumetric flask. Dilute to volume with distilled water which will dilute the 0.2 N HCl to 0.1 N HCl which is the electrolyte.

Transfer a 10-ml aliquot from the 50-ml volumetric flask into the polarographic cell, add 1 ml of 200 micrograms Cd per ml solution, and remove oxygen from the cell by bubbling nitrogen which is being purified as described under reagents, through for three to five minutes. The instrument used is a Sargent Polarograph - Model XXI and the settings are as follows: A.C. switch down (on), D.M.E. - up (negative), Damping - down (off), Initial E.M.F. - up (additive), D.C. E.M.F. - down (1.5 V span), Chart drive - up (on), Operation - up (E.M.F. increasing). The initial voltmeter is set at .3 volts, the span voltmeter is set at .6 volts, thereby giving a range from -.3 volts to -.9

volts. This is sufficient as lead "comes off" at approximately -.44 volts and cadmium at approximately -.66 volts. The sensitivity setting might have to be found by trial and error, 0.020 suffices for most samples although if the lead is low the sensitivity will have to be increased (decreasing the number of microamperes/mm).

If there is a possibility that Cd is present in the sample, an aliquot of the sample should be run in the polarographic cell first, without any internal standard added. If there is CD present in the sample this must be taken into account when Cd, the internal standard, is added.

Standard Curve - Into the polarographic cell is introduced 1 ml of 200 micrograms Pb per ml solution, 1 ml of 200 micrograms Cd per ml solution and 9 ml of 0.1 N HCl. This gives a total amount of solution in the cell of 11 ml thereby enabling a later removal of 10 ml of the sample and 1 ml of 200 micrograms Cd per ml internal standard solution. Also, there is an electrolyte in the cell of 0.1 N HCl. Both the volume of liquid in the cell and the electrolyte for standard curve and sample are critical for a proper analysis.

On the standard curve the heights of the Pb and Cd curves are measured in mm. The Pb to Cd ratio is found, which is divided by the number of micrograms of Pb used giving a factor for 1 microgram Pb versus 200 micrograms Cd. It is suggested that 200 micrograms Cd be used as an internal standard in each sample for Pb thereby simplifying the calculations. The factor for 1 microgram Pb versus 200 micrograms Cd, found at the beginning of the series of samples being analyzed, will be used for the calculations through this series.

(f) Calculations

For the sample "polarogram" the heights of the Pb and Cd curves are measured in mm and the Pb to Cd ratio found in the same manner as the standard curve. The ratio found here is divided by the factor found in the standard curve for 1 microgram Pb versus 200 micrograms Cd giving the number of micrograms of Pb in the aliquot put into the polarographic cell.

$$\text{mg Pb/M}^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions.

Mercury

Source: American Conference of Governmental Industrial Hygienists.

(a) Scope

Divalent mercury forms an orange-yellow complex with dithizone in dilute acid solution which can be extracted by chloroform. An additional extraction in the presence of chloride and bromide ions eliminates the interference of other metals.

(b) Auxiliary Apparatus

- Beckman DU Spectrophotometer or equivalent.
- Squibb separator funnels.
- Cuvettes.

(c) Reagents

HCl-0.1 N.

Meta Cresol Purple Indicator - Dissolve 0.05 g of the power in 6 ml of 0.05 N NaOH; then dilute to 100 ml with distilled water.

Buffer Solution - Dissolve 300 g anhydrous Na_2HPO_4 and 75 g K_2CO_3 in distilled water to make 2 liters of solution (MacIlvaine's Buffer Solutions).

Treated Chloroform - Chloroform treated with hydroxylamine hydrochloride as per the method of Hubbard, Industrial Engineering Chemistry, Anal. Ed., 9, 493 (1937).

Dithizone Solutions - Make up a stock solution containing 0.5 mg dithizone per ml of chloroform. Other strength dithizone solutions can be made up as needed. It is advisable to allow the dithizone solutions to stabilize overnight before use.

Potassium Bromide Solution - 40% KBr in distilled water.

Ammonium Citrate - 40%. Mix 40 g citric acid, monohydrate, with about 20 ml distilled water. Add sufficient ammonium hydroxide slowly with constant stirring to make solution alkaline to phenol red and make to volume with water. Purify by shaking with dithizone in chloroform and clear with pure chloroform.

Mercury Standard Solutions - Dissolve 0.1354 g mercuric chloride, C.P., special reagent grade in 1 N HCl and make up to 100 ml with the acid. This solution contains 1 mg Hg per ml and is quite stable. If any cloud or sediment develops, it should be discarded. Other strength solutions can be made by dilution with distilled water as the need arises.

Hydroxylamine Hydrochloride - 20% solution in distilled water.

(d) Sampling Procedure

Assemble sampling train of probe, impinger with 100 ml of 0.25% iodine in a 3% aqueous solution of potassium iodide. Sampling rate of 1 CFM for a period long enought to provide a minimum of 30 cubic feet at standard conditions.

(e) Analytical Procedure

Sample Preparation - The contents of the impinger flask and washings are made up to a known volume with distilled water. A proper aliquot is taken to place the mercury concentration within range of the method. Add 5 ml of ammonium citrate, 1 ml hydroxylamine hydrochloride and shake. Add 2 drops of phenol red indicator. (Always add the hydroxylamine hydrochloride before the phenol red.) Titrate with ammonium hydroxide to the full color end point pH of 8.5. Extract with 5 ml portions of 20 mg/liter dithizone solution, withdrawing the chloroform layers into another 250 ml Squibb separatory funnel, into which has been placed 50 ml of 0.1 N HCl. Continue to extract with and withdraw 5-ml portions until the dithizone in the chloroform layer does not change color.

Shake the above dithizone extract with 50 ml 0.1 N HCl for 2 minutes. Draw off the chloroform into a clean separatory funnel. Wash the aqueous phase with two, 3-5 ml portions of treated chloroform and add to the extracts. Discard the aqueous phase. To the chloroform extracts, add 50 ml of 0.1 N HCl and 10 ml of the 40% KBr reagent. Shake for 2 minutes. The Hg goes into the aqueous phase as H_2HgBr_4 while the Cu and Bi remains in the dithizone which is discarded. Wash the aqueous phase with a few ml of treated chloroform. Let the phases separate well and discard completely all chloroform droplets. An aliquot of the stripping solution may be taken if necessary so that the amount of Hg will fall on the standard curve. If an aliquot is taken, make up to 50 ml volume with 0.1 N HCl.

Add 10 ml buffer solution to bring the pH to 6, and 10 ml of 10 mg/liter dithizone solution. Shake well for 2 minutes. Avoid any exposure to direct sunlight or exceedingly bright artificial light.

NOTE: If the separatory funnel was not washed thoroughly with distilled water, the dithizone may be oxidized.

By means of a cotton swab on an applicator stick, remove any traces of moisture from the stem of the funnel after the stopcock has been opened for a second to allow the chloroform to fill the bore. Loosely insert a small cotton plug in the stem of the funnel. Rinse a cuvette twice with 1-2 ml portions of the chloroform layer and draw off the remaining dithizone into the cuvette. Place in the spectrophotometer and read at point of maximum light absorption (485 millimicron) against distilled chloroform. A blank on reagents should be carried through the entire procedure and this blank subtracted from the final result.

Standard curve - Suitable concentrations of mercury to give coverage over the entire range are used to establish a particular curve. Three or four points are sufficient.

Place 5 ml of the 40% KBr reagent, 10 ml of the buffer solution and the proper amount of standard mercury solution in a 125 ml Squibb separatory funnel. Add enought 0.1 N HCl to make the final volume 65 ml. Then add 10 ml of 10 mg/liter dithizone solution and shake for 2 minutes. Flush the stem of the separatory funnel and remove moisture by means of a cotton swab, withdraw the chloroform layer and read in the spectrophotometer as described above.

The 10 mg/liter dithizone solution is of sufficient strength to cover the range from 0 to 15 micrograms of mercury. By using 20 ml instead of the standard 10 ml of this reagent, the concentration range covered can be doubled. It is not recommended to add more than 20 ml of 10 mg/liter dithizone to any sample.

For only an occasional mercury analysis, it is better to bracket the sample with standard amounts rather than prepare an entire curve.

(f) Calculation

$$\text{mg Hg/M}^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Zinc

Source: Michigan Department of Public Health.

(a) Scope

Stack testing for zinc can be accomplished by the polarograph method using a dropping-mercury electrode with the sample as the electrolyte.

(b) Auxiliary Apparatus

Sargent Polarograph - Model XXl, recording type, or equivalent.

(c) Reagents

Stock Zinc Solution - Weigh exactly 5.0 grams of dry reagent zinc (30 mesh or finer) into a 500-ml volumetric flask and add a minimum amount of constant boiling hydrochloric acid to get the zinc in solution. Boil until solution is complete and make up to volume with distilled water. The solution contains 10.0 mg zinc per ml.

Working Standard Zinc Solution - Pipette 5.0 ml of stock zinc solution (10.0 mg zinc per ml) into 500-ml volumetric flask and take to volume with 0.2 M KCl. The solution contains 100 micrograms zinc per ml with 0.2 M KCl as the electrolyte.

0.2 M KCl Solution - Weigh 14.9 grams reagent grade KCl into 1 liter volumetric flask and take to volume with distilled water.

Standard Cadmium Solution - Weigh exactly 0.2744 grams of $Cd(NO_3)_2 \cdot 4H_2O$ into a 500-ml volumetric flask and take to volume with 0.2 M KCl. The solution contains 200 micrograms Cd per ml with 0.2 M KCl as electrolyte.

Oxygen Absorbent for Purification of Nitrogen - Pass nitrogen through a first scrubbing flask (midget impinger) containing concentrated NH_4OH and copper turnings. Caution: Make certain hole in impinger is not plugged before turning nitrogen on under pressure. Then pass nitrogen through a second scrubbing flask containing concentrated sulfuric acid, again making certain this is not plugged before applying pressure.

Clean, Dry Mercury - Purchase from Eberbach & Son.

(d) Sampling Procedure

Assemble sampling train of probe, impinger with 100 ml 5% nitric acid solution, flow meter and vacuum pump. Sample at rate of 1 CFM for a period long enough to provide a minimum of 30 cubic feet at standard conditions.

(e) Analytical Procedure

Sample Preparation - Transfer the collecting solution from the impinger into a 250 ml beaker, wash out impinger with 5% hot nitric acid and all taken down to dryness on a hot plate. Add 2 ml concentrated nitric acid, wetting the sample thoroughly. Add 6 drops perchloric acid and swirl to mix. Evaporate to dryness on a hot plate at 350°-400° C. Repeat the acid treatment to obtain complete digestion. Cool and add 10 ml of 0.2 M potassium chloride solution. Loosen the solids with a rubber policeman, rinse policeman and beaker walls with 3-5 ml of 0.2 M potassium chloride solution. Cover with a watch glass and boil 2-3 minutes. Filter the solution into a 50-ml volumetric flask washing the filter with 0.2 M KCl. Dilute to volume with 0.2 M KCl giving the sample in 50 ml with 0.2 M KCl as the electrolyte.

Transfer 10 ml aliquot into polarographic cell, add 1 ml of 200 micrograms Cd per ml solution, and remove oxygen from cell by bubbling nitrogen through for three to five minutes. The initial voltmeter is set at .4 volts, the span voltmeter is set at 1 volt, thereby giving a range from -.4 volts to -1.4 volts. This is sufficient as cadmium "comes off" at approximately -.66 volts and zinc at approximately -1.05 volts. The sensitivity setting will vary depending on the amount of zinc present. The setting used for the standard curve is 0.02 microamperes/mm.

If there is a possibility that Cd is present in the sample an aliquot of the sample should be run in the polarographic cell first, without any internal standard added. If there is Cd present in the sample this must be taken into account when CD, the internal standard, is added.

Standard curve - Into the polarographic cell is introduced 1 ml of 100 micrograms Zn per ml solution, 1 ml of 200 micrograms Cd per ml solution, and 9 ml of 0.2 M KCl solution. This gives a total amount of solution in the cell of 11 ml thereby enabling a later removal of 10 ml of the sample and 1 ml of 200 micrograms Cd per ml internal standard solution. Also, there is an electrolyte in the cell of 0.2 M KCl. Both the volume of liquid in the cell and the electrolyte for standard curve and sample are critical for a proper analysis.

On the standard curve the heights of the Zn and Cd curves are measured in mm. The Zn to Cd ratio is found which is divided by the number of micrograms of Zn used giving a factor for 1 microgram Zn versus 200 micrograms Cd. It is suggested that 200 micrograms Cd be used as an internal standard in each sample for Zn thereby simplifying the calculations. The factor for 1 microgram Zn versus 200 micrograms Cd, found at the beginning of the series of samples being analyzed, will be used for the calculations through this series.

(f) Calculations

For the sample "polarogram" the heights of the Zn and Cd curves are measured in mm and the Zn to Cd ratio found in the same manner as the standard curve. The ratio found here is divided by the factor found in the standard curve for 1 microgram Zn versus 200 micrograms Cd giving the number of micrograms of Zn in the aliquot put into the polarographic cell.

$$\text{mg Zn/M}^3 = \frac{V \cdot Y}{1{,}000 \cdot v \cdot Va}$$

where v = aliquot (ml)
V = total sample (ml)
Y = micrograms in v
Va = gas sample volume, in cubic meters, at standard conditions

Nitrogen Oxides, Phenoldisulfonic Acid Method

Source: Public Health Service.

(a) Scope

When sulfur dioxide, ammonia, iron or other compounds that interfere with the hydrogen peroxide method are present in the gas to be sampled and/or the concentration of the nitrogen oxides is below about 100 ppm, this method is used. Accuracy below 5 ppm is questionable. This test is unsuitable for atmospheric sampling.

(b) Apparatus

- Sampling Probe - Stainless steel (type 304 or 316) or glass tubing of suitable size (1/4-inch-OD, 6-foot-long stainless steel tubing has been used).

- Collection Flask - A 2-liter round-bottom flask with an outer 24/40 joint for integrated samples or a 250-ml MSA sampling tube for grab samples.

- Orifice Assembly - The size of the glass capillary tubing depends on the desired sampling period (flow rates of about 1 liter per minute have been used). Use of this orifice is not mandatory.

- Adapter with Stopcock - Adapter for connecting collection flask to sampling "T".

- Three-way Stopcock.

- Manometer - A 36-inch Hg manometer or accurate vacuum gage.

- Spectrophotometer - Beckman Model "B" or equivalent.

(c) Reagents

Thirty Percent Hydrogen Peroxide - (reagent grade).

Three Percent Hydrogen Peroxide - Dilute 30% H_2O_2 with water at 1:10 ratio. Prepare fresh daily.

Concentrated Sulfuric Acid.

0.1 N (approximate) Sulfuric Acid - Dilute 2.8 ml concentrated H_2SO_4 to 1 liter with water.

Absorbing Solution - Add 12 drops 3% H_2O_2 to each 100 ml 0.1 N H_2SO_4. Make enough for required number of tests.

1 N (approximate) Sodium Hydroximde - Dissolve 40 gm NaOH pellets in water and dilute to 1 liter.

Concentrated Ammonium Hydroxide.

Fuming Sulfuric Acid - 15 to 18 weight percent free sulfuric anhydride (oleum).

Phenol (reagent grade).

Phenoldisulfonic Acid Solution - Dissolve 25 grams of pure white phenol in 150 ml concentrated H_2SO_4 on a steam bath. Cool and add 75 ml fuming sulfuric acid. Heat to 100° C for 2 hours. Store in a dark stoppered bottle. This solution should be colorless if prepared with quality reagents.

Potassium Nitrate (reagent grade).

Standard Potassium Nitrate Solution - Solution A: Dissolve 0.5495 gram KNO_3 and dilute to 1 liter in a volumetric flask. Solution B: Dilute 100 ml of Solution A to 1 liter. One ml of Solution A contains the equivalent of 0.250 mg NO_2 and of Solution B, 0.0250 mg NO_2.

(d) Sampling Procedure

Integrated Grab Sample - Add 25 ml freshly prepared absorbing solution into the flask. Record the exact volume of absorbing solution used.

Set up the apparatus as shown in Figure 3, attach the selected orifice. Purge the probe and orifice assembly with the gas to be tested before sampling begins by applying suction to it. Evacuate the system to the vapor pressure of the solution: this pressure is reached when the solution begins to boil. Record the pressure in the flask and the ambient temperature. Open the valve to the sampling probe to collect the sample. Constant flow will be maintained until the pressure reaches 0.53 of the atmospheric pressure. Stop before this point is reached. During sampling, check the rate of fall of the mercury in one leg of the manometer in case clogging, especially of the orifice, occurs. At the end of the sampling period, record the pressure, temperature, and barometric pressure.

An extended period of sampling can be obtained by following this procedure. Open the valve only a few seconds at regular intervals. For example: Open the valve for 10 seconds and close it for 50 seconds; repeat every 60 seconds.

Grab Sample - Set up the apparatus as shown in Figure 4 for high concentrations (200-3000 ppm) or the apparatus as shown in Figure 4 for low concentrations (0-200 ppm) but delete the orifice assembly. The same procedure is followed as in the integrated method except that the valve is opened at the source for about 10 seconds and no orifice is used.

Calibration curves are made to cover different ranges of concentrations. Using a microburette for the first two lower ranges and a 50-ml burette for the next two higher ranges, transfer the following into separate 150-ml beakers (or 200-ml casseroles).

1. 0-100 ppm: 0.0 (blank), 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 16.0, 20.0 ml of KNO_3 Solution B.

2. 50-500 ppm: 0.0 (blank), 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0 ml of KNO_3 Solution A.

3. 500-1500 ppm: 0.0 (blank), 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 ml of KNO_3 Solution A.

4. 1500-3000 ppm: 0.0 (blank), 15.0, 30.0, 35.0, 40.0, 45.0, 50.0, 55.0, 60.0 ml KNO_3 Solution A.

Add 25.0 ml absorbing solution to each beaker. Follow as directed in the Analytical Procedure section starting with the addition of 1 N NaOH.

After the yellow color has developed, make dilutions for the following ranges: 50 to 500 ppm (1:10); 500 to 1,400 ppm (1:20); and 1,500 to 3,000 ppm (1:50). Read the absorbance of each solution at 420 millimicron.

Plot concentrations against absorbance on rectangular graph paper. A new calibration curve should be made with each new batch of phenoldisulfonic acid solution or every few weeks.

(e) Analytical Procedure

Shake the flask for 15 minutes and allow to stand over night.

Transfer the contents of the collection flask to a beaker. Wash the flask three times with 15-ml portions of H_2O and add the washings to the solution in the beaker. For a blank add 25 ml absorbing solution and 45 ml H_2O to a beaker. Proceed as follows for the bank and samples.

Add 1 N NaOH to the beaker until the solution is just alkaline to litmus paper. Evaporate the solution to dryness on a water bath and allow to cool. Carefully add 2 ml phenoldisulfonic acid solution to the dried residue and triturate thoroughly with a glass rod, making sure that all the residue comes into contact with the solution. Add 1 ml H_2O and four drops concentrated H_2SO_4. Heat the solution on the water bath for 3 minutes, stirring occasionally.

Allow to cool and add 20 ml H_2O, mix well by stirring, and add 10 ml concentrated NH_4OH, dropwise, stirring constantly. Transfer the solution to a 50-ml volumetric flask, washing the beaker three times with 4- to 5-ml portions of H_2O. Dilute to mark with water and mix thoroughly. Transfer a portion of the solution to a dry, clean centrifuge tube and centrifuge, or filter a portion of the solution.

Read the absorbance of each sample at 420 millimicron. If the absorbance is higher than 0.6, make a suitable dilution of both the sample and blank and read the absorbance again.

(f) Calculations

$$\text{ppm } NO_2 = \frac{(5.24 \times 10^5)\ (C)}{V_s}$$

Where C = concentration of NO_2, mg (from calibration chart)

V_s = gas sample volume at 70° F and 29.92 in Hg, ml.

Sulfur Dioxide and Sulfur Trioxide, Shell Development Company Method

Source: National Air Pollution Control Administration Publication 999-AP-13.

(a) Scope

This method describes a procedure for determining sulfur dioxide and sulfur trioxide in stack gases.

(b) Apparatus

- Sampling Probe	- Glass tubing (preferably borosilicate or quartz) of suitable size with a ball joint at one end and a removable filter at the other (a 1/2-inch-OD, 6-foot-long tube has been used.)
- Filter	- A filter is needed to remove particulate matter, which may contain metal sulfates and cause interference during analysis. Borosilicate glass wool, Kaolin wool, or silica wool are suitable filters for removing particulate matter.
- Adapter	- Six plug-type connecting tubes T 24/40, one with a 90° bend and a socket joint.
- Heating Tape	- An insulated heating tape with a powerstat to prevent condensation in exposed portion of probe and adapter. Alternative: glass wool or other suitable insulators.
- Dry Gas Meter	- A 0.1-cubic-foot-per-revolution dry gas meter equipped with a fitting for a thermometer and a manometer. Alternately, a calibrated tank or a rotameter calibrated at the operating pressure may be used.
- Vacuum pump.	
- Thermometers	- One 10°-50° C, ± 1° C; and one 0°-300° C ± 5° C are suitable.
- Manometer	- A 36-inch-Hg manometer
- Absorbers	- Two U-shaped ASTM D 1266 lamp sulfur absorbers with coarse-sintered plates.

- Filter Tube	-	One 40-mm-diameter Corning medium-sintered plate.
- Scrubber for Purifying Air	-	An ASTM D 1266 lamp sulfur absorber with coarse-sintered plate.
- Teflon Tubing	-	Teflon tubing, 1/4-inch ID, for connecting absorbers. Alternative: 8-mm pyrex tubing with butt-to-butt connections held together with Tygon.

(c) Reagents

Water - Distilled water that has been deionized.

Isopropanol, Anhydrous.

Eighty Percent Isopropyl Alcohl - Dilute isopropanol with water at a ratio of 4 to 1.

Thirty Percent Hydrogen Peroxide - (reagent grade).

Three Percent Hydrogen Peroxide - Dilute 30% hydrogen peroxide with water at a ratio of 10 to 1. Prepare fresh daily.

Barium Chloride - ($BaCl_2 \cdot 2H_2O$, reagent grade).

0.0100 N Alcoholic Barium Chloride - Dissolve 1.2216 grams $BaCl_2 \cdot 2H_2O$ in 200 ml of water and dilute to 1 liter with isopropanol. Standardize this solution with 0.01 N alcoholic sulfuric acid solution.

(As an alternate titrating solution to 0.01 N alcoholic barium chloride, in American Petroleum Institute Study Group uses 0.01 N alcoholic barium perchlorate because they believe that it gives a sharper end point during titration.)

Thorin Indicator - 1-(0-arsonophenylazo)-2 naphthol-3, 6-disulfonic acid, disodium salt.

0.2 Percent Thorin Indicator - Dissolve 0.2 gram thorin indicator in 100 ml water. Store in polyethylene bottle.

(d) Sampling Procedure

Set up the apparatus as shown in Figure 5. Place 30 ml of 80% isopropyl alcohol in the first absorber and 10 ml in the filter tube. The add 50 ml of 3% hydrogen peroxide to the second absorber. A light film of silicone grease on the upper parts of the joints may be used to prevent leakage. Wind the heating tape in a uniform single layer around the exposed portion of the probe and adapter and cover the heating tape with asbestos tape wound in the opposite direction. Place a thermometer between the heating tape and asbestos as near the adapter joint as possible. Connect the heating tape to a powerstat, switch on the current, and maintain the probe and adapter at a temperature at which no condensation will occur (about 250° C). Sample at 0.075 cubic foot per minute until 2 cubic feet or a suitable volume of gas has been sampled. Record the meter readings, temperatures and pressures at

10-minute intervals. Note the barometric pressure. Do not sample at a vacuum of more than 8 inches Hg.

Disconnect the asbestos tape, heating tape, probe, and adapter and allow them to cool. Connect the scrubber for purifying air to the inlet of the isopropyl alcohol absorber and add 50 ml of 3% hydrogen peroxide. Replace the water in the ice bath with tap water. Draw air through the system for 15 minutes to transfer residual sulfur dioxide to the hydrogen peroxide absorber. Disconnect the purifying air scrubber. (Although the use of air for removal of sulfur dioxide from isopropyl alcohol should not result in oxidation of sulfur dioxide to sulfur trioxide, the American Petroleum Institute Joint Study Group uses 99% nitrogen to preclude any possibility of oxidation.) Remove the filter and wash the probe and adapter with 80% isopropyl alcohol. Place the washings in the isopropyl alcohol absorber.

Disconnect the hydrogen peroxide absorber and transfer the contents and the water washings to a 250-ml volumetric flask. Dilute the water to the mark. Analyze for sulfur dioxide.

Stopper the isopropyl alcohol absorber and apply suction to the filter end. Remove the suction line and allow the partial vacuum in the absorber to draw the solution from the filter. Rinse the filter tube with 80% isopropyl alcohol before the suction is lost. Transfer the contents of the isopropyl alcohol absorber and its washings to a 250-ml volumetric flask and dilute to the mark with 80% isopropyl alcohol. Analyze for sulfur trioxide.

(e) Analytical Procedure

Sulfur Trioxide - Pipette a suitable aliquot to a flask and dilute to 100 ml with 80% isopropyl alcohol. Add a few drops of thorin indicator (enough to give a yellow color). Titrate with 0.01 N $BaCl_2$ to the pink end point. Make a blank determination in parallel.

Sulfur Dioxide - Transfer a suitable aliquot to a flask and add 4 times this volume of isopropyl alcohol. Dilute to 100 ml with 80% isopropyl alcohol, add enough thorin indicator to give a yellow color, an titrate with standard 0.01 N $BaCl_2$ to the pink end point. Run a blank determination in parallel.

(f) Calculations

$$\text{ppm } SO_2 \text{ or } SO_3 \text{ by volume} = \frac{24(A-B)\ (N)\ (F)\ (T)}{(V_o)\ (P)}$$

Where A = 0.01N $BaCl_2$ used for titration of sample
B = ml 0.01N $BaCl_2$ used for titration of blank
N = exact normality of $BaCl_2$
F = dilution factor
T = average meter temperature, ^{o}R
V_o = observed volume of gas sample, cu ft
P = average absolute meter pressure, in. Hg

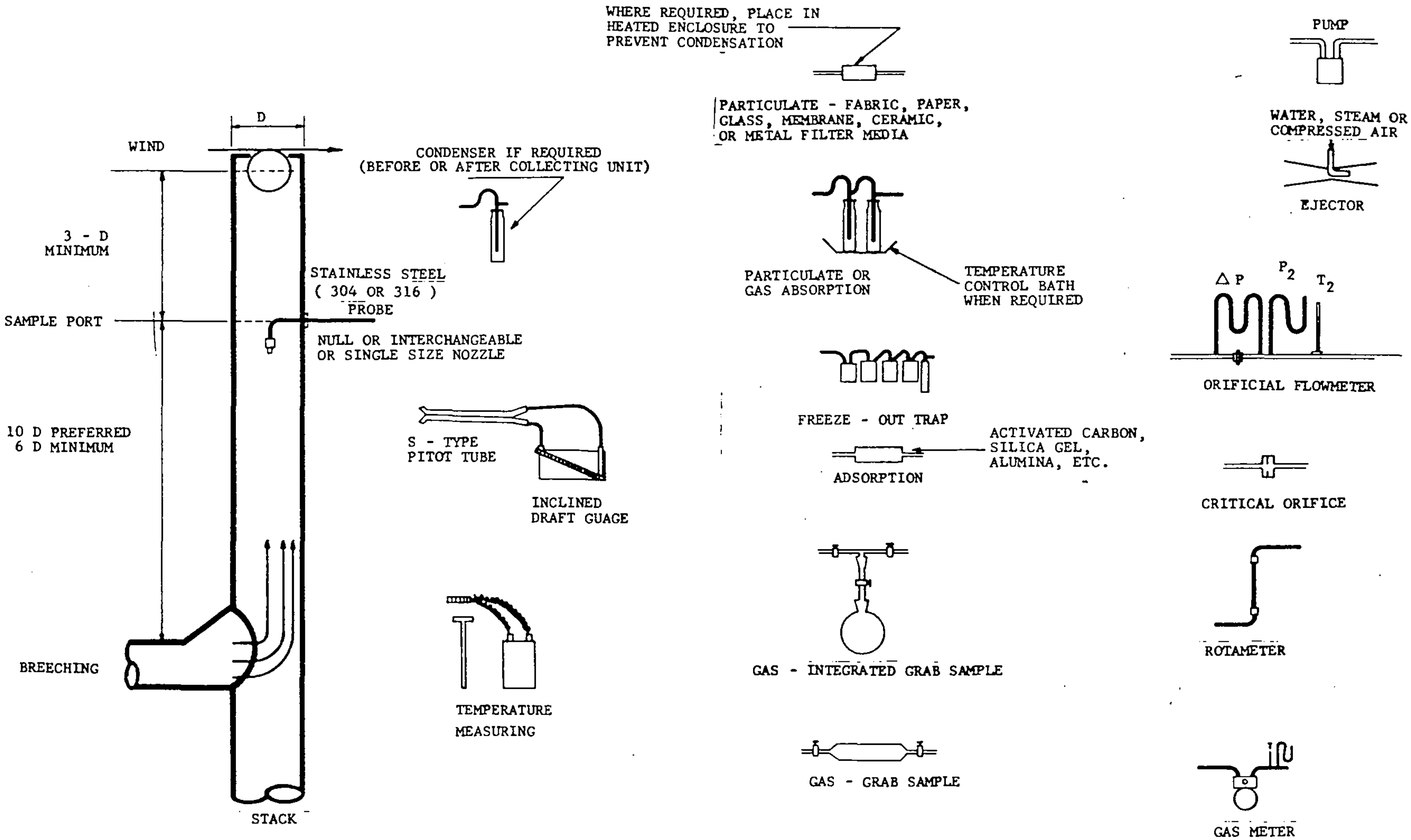
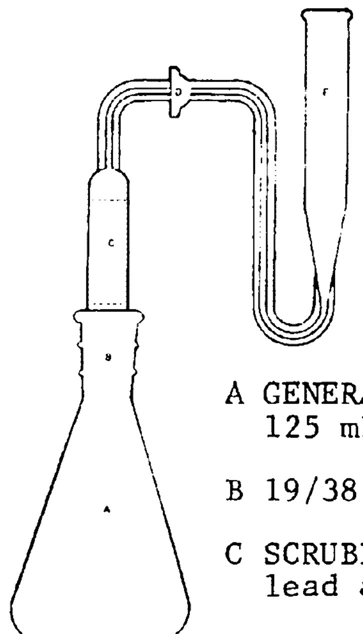


FIG. 1 SAMPLING LOCATION & TRAIN COMPONENTS

APPENDIX A
Figure I



A GENERATOR
125 ml Erlenmeyer

B 19/38

C SCRUBBER
lead acetate on pyrex wool

D 12/2 ball joint

E ABSORBER
12 ml heavy wall
centrifuge tube

FIGURE 2

Arsine Generator

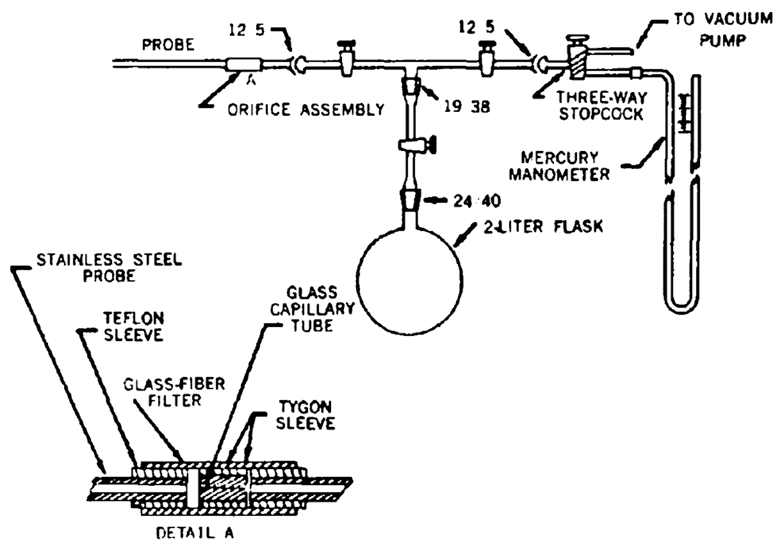


FIGURE 3

APPARATUS FOR INTEGRATED GRAB SAMPLES

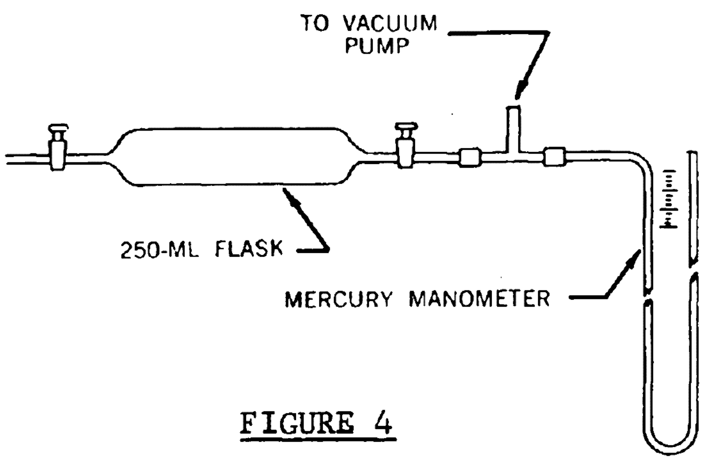


FIGURE 4

APPARATUS FOR GRAB SAMPLES

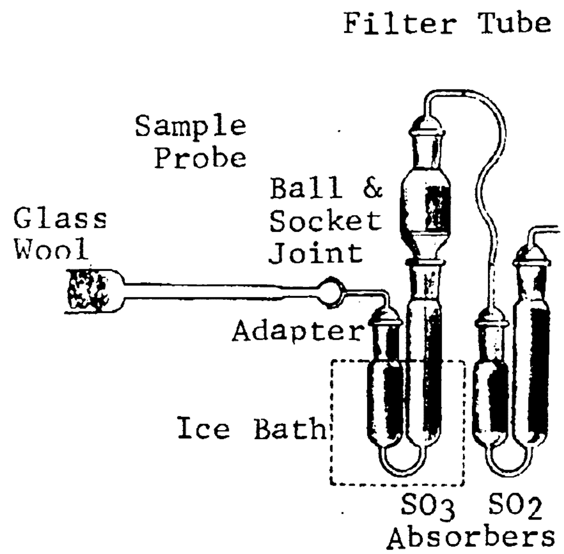


FIGURE 5

Sulfur dioxide - sulfur trioxide sampling train.

Budget Bureau No. 85-S69044
Approval expires: Sept. 30, 1970

Date:____________________ Team:_____________

SYSTEMS ANALYSIS OF EMISSIONS AND EMISSIONS CONTROL IN THE IRON FOUNDRY INDUSTRY

INTERVIEW GUIDE FOR IN-PLANT ENGINEERING SURVEY

BY

A. T. Kearney & Company, Inc.

For

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
Contract CPA 22-69-106

IDENTIFICATION

A. Name and location of company AFS Code__________

1. Name________________________________
2. Number and Street__________________ 3. County________
4. City____________ 5. State __________ 6. Zip Code ________

B. Location of foundry if different from above

1. Number and Street________________________________
2. City____________________________ 3. County________
4. State___________________________ 5. Zip Code ________

C. Person to contact regarding this report

1. Name__________________________ 2. Area Code/ Phone ____________

AFS Code__________ Zip Code __________

Section I - GENERAL INFORMATION

1. Type of Metal Cast

	Metal Cast	Percent Cast	Tons/Month Melt
1.___	Gray Iron		
2.___	Malleable Iron		
3.___	Ductile Iron		

2. Average number of production workers for 1968.
   - ☐ 1. Under 10
   - ☐ 2. 10-49
   - ☐ 3. 50-249
   - ☐ 4. Over 250

3. To what industry do you supply castings?
   - ☐ 1. Automotive
   - ☐ 2. Agricultural
   - ☐ 3. Cast Iron Pipe
   - ☐ 4. Industrial and Electrical Equipment
   - ☐ 5. Valves and Fittings
   - ☐ 6. Jobbing

4. Weight range of castings produced.
   - ☐ 1. Under 10 lbs.
   - ☐ 2. 10-49
   - ☐ 3. 50-99
   - ☐ 4. 100-500
   - ☐ 5. Over 500 lbs.

5. What is the basic product cast. (i.e., Brake drum, pipe, machinery bases, railroad, etc.)________________________

____

6. CHARACTERISTICS OF FURNACE

FURNACE NUMBER	FURNACE TYPE CODE 1 - CUPOLA 2 - CHANNEL IND. 3 - CORELESS IND 4 - DIRECT ARC 5 - INDIRECT ARC 6 - AIR FURNACE 7 - OTHER (SPECIFY)	LINING OR COIL 1-ACID 2-BASIC 3-NEUTRAL 4-UNLINED 5-SIN OPEN CH. 6-SIN CLOSED CHANNEL 7-DOUBLE CHANNEL	USE CODE 1 - MELT 2 - HOLD 3 - DUPLEX	SIZE FURNACE LINED DIAMETER, INCHES	SIZE HOLDING CAPACITY, TONS	MODEL MANUFACTURER & MODEL NUMBER	MELT RATE AVERAGE DAILY MELT RATE TON/HR.	UTILIZATION HR/DAY MELTING	UTILIZATION HR/DAY POURING	UTILIZATION HR/DAY OTHER	BLAST TYPE 1 - HOT 2 - WARM 3 - COLD	BLAST VOL. & PRESS VOLUME, SCFM AND PRESSURE, OZ. WATER	BLAST TEMP. DEGREES FAHRENHEIT	CHARGE DOOR SIZE, SQ. FT.	CHARGE DOOR 1 - OPEN 2 - CLOSED *	HEIGHT CHARGING DOOR SILL ABOVE FLOOR, FEET	PREHEAT CHARGE 1-PREHEAT 2-DRIED 3-BOTH 4-NONE	FUEL INJECTION OR OXYGEN ENRICHMENT 1 - NATURAL GAS 2 - OXYGEN 3 - OTHER(SPECIFY)	FUEL INJECTION OR OXYGEN ENRICHMENT CFM-OXYGEN BTU/HR.-GAS	AFTERBURNERS NUMBER	AFTERBURNERS SIZE, BTU/HR.	AFTERBURNERS LOCATION 1 - ABOVE DOOR 2 - BELOW DOOR	AFTERBURNERS DISTANCE AFTER-BURNER TO GAS TAKE-OFF, INCHES	POWER SUPPLY, KW.	CHARGING 1 - TOP 2 - SIDE
1																									
2																									
3																									
4																									
5																									
6																									
7																									
8																									
9																									
10																									

NOTES:

* 1. IF CLOSED, DESCRIBE CONSTRUCTION, CONTROL STATION, FAIL SAFE FEATURES, ETC.

2. NOTE NATURE OF BLAST HEATING, E.G., RECUPERATIVE, EXT. FIRED, RECUP. & EXT. FIRED.

3. NOTE WHETHER LINE, MEDIUM OR HIGH FREQUENCY FOR CORELESS INDUCTION.

AFS Code ____________

7. Characteristics of charge for each furnace

Charge	Furnace Number 1	2	3	4	5	6
a. Metallic (lbs. Total)						
1. Remelt						
2. Pig Iron						
3. Purchased Cast Iron						
4. Purchased Steel						
5. Briquettes						
6. Punchings and/or Turnings						
b. Fluxes (lbs. Total)						
1. Limestone						
2. Dolomite						
3. Soda Ash						
4. Fluorspar						
5. Other (specify)						
c. Carbo-coke (lbs.)						
d. Additives (lbs. Total)						
1.						
2.						
3.						
4.						
e. Metal to Coke Ratio						
f. Sulphur Content of Coke, %						
g. Desulphurizing Agents (lbs)						
1. Caustic Soda						
2. Soda Ash						
3. Other (specify)						
h. Quality of Scrap 1. Rusty 3. Oily 2. Dirty 4. Clean						
i. Charging Method (Bucket, etc.)						

AFS Code __________

8. How is the scrap prepared and treated? ______________________________

____

____

9.

Stack Analysis	Furnace Number					
	1	2	3	4	5	6
% CO						
% CO_2						
% N_2						
Stack Gas Temp. @ Top of Burden, °F						

10. Alloy additions to the ladle

Operation	Type	Additions in lbs.	Ladle Size Tons
Nodularization			
Alloys	1. 2. 3. 4.		
Other	1. 2.		

11. Average length of time for "light-up" per day, min. __________

12. Method of light-up

- ☐ 1. Wood
- ☐ 2. Gas
- ☐ 3. Oil
- ☐ 4. Electric
- ☐ 5. Other (specify)

AFS Code ___________

13. Have you in the last ten years replaced cupolas?

a. Type of furnace.

☐ 1. Electric Arc

☐ 2. Induction, Coreless

☐ 3. Induction, Channel

☐ 4. Other (specify)

b. When, 19____

c. Reason ____

____

14. Pouring Smoke Control

a. Furnace Tapping

1. Ventilation

☐ 1. General

☐ 2. Local

2. Effectiveness

☐ 1. Excellent

☐ 2. Good

☐ 3. Fair

b. Mold Pouring

1. Ventilation

☐ 1. General

☐ 2. Local

2. Effectiveness

☐ 1. Excellent

☐ 2. Good

☐ 3. Fair

Section III - CONTROL SYSTEM

15. Identification of control system. Complete columns (b) through (g) for each control system.

Control Number (a)	Control System (b)			Furnace(s) Controlled (c)			Year Installed (d)	Gas Vol. cfm (e)	Gas Temp. °F (f)	Pressure Drop Inches Water (g)
1							19__			
2							19__			
3							19__			
4							19__			

(a) Control System Identification Number is for reference in succeeding items.

(b) Type of control system. Please use the following code:

System	Code
Fly ash and spark arrester	1
Afterburner	2
Wet Cap	3
Mechanical Collector	4
Wet Scrubber	5
Fabric Filter	6
Electrostatic Precipitator	7

Where a control system consists of several pieces of connected equipment such as an afterburner, mechanical collector, and electrostatic precipitator indicate the sequence by 2/4/7.

(c) Furnaces serviced by the control system. Use the furnace identification number from Item 6. Furnaces not listed here will be assumed to have no control system.

(d) Year the control system was installed

(e) Rated gas volume in std. dry cubic feet per minute at the exhauster inlet.

(f) Gas temperature at the exhauster inlet in degrees fahrenheit.

(g) Static pressure drop through the exhauster in inches of water.

AFS Code ____________

16. Characteristics of the control systems. Complete the applicable items below:

	Control Systems			
	1	2	3	4
a. Height of exhaust stack above ground level (ft.)				
b. Combustion chamber size in Btu's/hour				
c. Water consumption in gallons/min. 1. Dust collector				
2. Gas cooling				
3. Recirculated				
d. Noise control (✓)				
e. Heat exchanger. Type or make				
f. Type of filter media Media 1. Natural fibre 2. Synthetic fibre 3. Glass fibre				
g. Air to cloth ratio				
h. Effluent and gas take-off Take-off 1. Above charging door 2. Below charging door 3. Into side draft hood 4. " full roof hood 5. " canopy hood 6. " snorkel 7. Direct shell evaluation 8. None				

AFS Code____________

17. Operation of control system

Report below for each control system.

	Control System			
	1	2	3	4
a. Particulate Concentration				
1. Inlet, gr/dry scf., lbs./1000 lbs. gas, lb./hr.				
2. Outlet, gr/dry scf., lbs./1000 lbs. gas, lb./hr.				
b. Catch, lb. Dust/Ton Melt				
c. Collection Efficiency, %				
d. Melt rate at which measurements were made, Ton/hr.				
e. Particle Proportion, % Distribution				
1. Less than 2 microns				
2. " " 5 microns				
3. " " 10 microns				
4. " " 20 microns				
5. " " 50 microns				
6. " " 100 microns				
7. " " 200 microns				
8. " " 500 microns				
9. " " 1000 microns				
f. Gas Analysis, %				
1. CO_2				
2. CO				
3. O_2				
4. N_2				
5. H_2				
6. SO_2				
7. H_2O				
g. Catch Proportion, %				
1. Less than 2 microns				
2. " " 5 microns				
3. " " 10 microns				
4. " " 20 microns				
5. " " 50 microns				
6. " " 100 microns				
7. " " 200 microns				
8. " " 500 microns				
9. " " 1000 microns				
h. Chemical Composition of Catch, %				
1.				
2.				
3.				
4.				
5.				
6.				
7.				
i. Combustible Analysis				
1.				
2.				
3.				

AFS Code___________

18. Controlled non-melting operations

Foundry Operation (a)	Control System (b)	Control Equipment: Type (c)	Year Installed (d)	Rated Size (cfm) (e)	Collection (#/week) (f)	Collection Efficiency(%) (g)
			19____			
			19____			
			19____			
			19____			
			19____			
			19____			

From the following list indicate in column (a) above, the code number of each of the operations in which your foundry employs air pollution control equipment.

Operation	Code
Metal pouring and mold cooling	1
Coremaking operations	2
Sand drying and sand reclamation	3
Sand conditioning	4
Sand handling	5
Mold and casting shakeout and conveying	6
Abrasive cleaning	7
Tumbling operations	8
Grinding operations	9
Annealing and heat treating furnaces	10
Pattern shop sawdust and chip systems	11
Casting surface coating	12
Welding	13

In column (c) above indicate the code number for the type of control equipment.

Control Equipment	Code
Afterburner	1
Mechanical collector	2
Wet scrubber	3
Fabric filter	4

AFS Code_______________

19. For the operations listed below provide the following: Capacities, number of units, and equipment types.

Operation	Number of Units	Capacity	Equipment Type and Size
a. Molding			
Automatic Molding Lines			
Molding Machines			
Sand Slingers			
Other (specify)			
b. Sand Conditioning Systems			
c. Core Room			
Batch Ovens			
Tower Ovens			
Horizontal Oven			
Core Blowers			
Molding Machine			
Core Sand Plant			
Other (specify)			
d. Shakeouts			
Mechanical			
Manual			
e. Cleaning Rooms			
Shot Blast Machines			
Tumbling Barrels			
Grinders			
Other (specify)			
f. Heat Treatment			
Oil Fired Ovens			
Gas Fired Ovens			
Oil Quench			
g. Paint Booths			

Section IV - COSTS OF POLLUTION CONTROL

20. Investment costs. Report on lines 1 - 5, the designated costs associated with each of the control systems.

Investment Cost Categories	Control Systems on Furnaces				All Other Control Systems
	1 (a)	2 (b)	3 (c)	4 (d)	(e)
1. Basic Equipment					
2. Auxiliary Equipment					
3. Engineering					
4. Installation					
5. Total					

Described below are examples of the items to be included in each type of investment cost. The column headed "All Other Control Systems" should include investment cost totals for all non-melting control systems as reported in item 18.

1. Basic equipment. Include taxes and shipping charges with F.O.B. price on the "flange to flange" costs of basic equipment. If you manufactured the basic control equipment, estimate the cost of fabrication.

2. Auxiliary equipment. Include the following items essential to the successful operation of a control system but not generally manufactured by gas cleaning equipment suppliers:

   a. Air movement equipment
      (1) Fans and blowers
      (2) Electrical; motors, starters, wire conduit, switches, etc.
      (3) Hoods, duct works, gaskets, dampers, etc.

   b. Liquid movement equipment
      (1) Pumps
      (2) Electrical; motors, starters, wire conduit switches, etc.
      (3) Piping and valves
      (4) Settling tanks

   c. Storage and disposal equipment
      (1) Dust storage hoppers
      (2) Sludge pits
      (3) Draglines, trackway, roadway, etc.

d. Support construction
   (1) Structural steel work
   (2) Cement foundation, piers, etc.
   (3) Insulation (therman)
   (4) Vibration and/or anti wear materials
   (5) Protective cover

e. Instrumentation: measurement and/or control of:
   (1) Air and/or liquid flow
   (2) Temperature and/or pressure
   (3) Operation and capacity
   (4) Power
   (5) Opacity of flue gas (smoke meters, etc.)

3. Engineering. Allocate the cost of research and engineering expenditures required for the selection of the specific control system, including such items as: material specifications, gas stream measurements, pilot operations, etc.

4. Installation. Include the following items when applicable:

   Labor to install
   Cleaning the site
   Yard and underground
   Building modification
   Design contingency
   Inspection
   Field contingency
   Overtime
   Existing facilities protection
   Supervision and engineering
   Field Office charges
   System start-up
   Profit reduction attributable to plant shutdown for installation

AFS Code____________

21. Annual costs.
Report in lines 1 - 6 the designated annual costs associated with each of the control systems.

Annual Cost Categories	Control Systems on Furnaces				All Other Control Systems
	1 (a)	2 (b)	3 (c)	4 (d)	(e)
1. Operating					
2. Maintenance					
3. Depreciation					
4. Overhead					
5. Process and equipment changes					
6. Total					

Described below are examples of the items to be included in each type of annual cost. The column headed "All Other Control Systems" should include annual cost totals for all non-melting control systems in item 18.

Annual Cost Categories

1. Operating costs
   a. Utilities needed to operate such as electricity, water, and gas
   b. Waste disposal operations
   c. Materials consumed in operating the system

2. Maintenance costs include labor and materials for:
   a. Replacement of parts and equipment
   b. Supervision and engineering
   c. Repairs
   d. Lubrication
   e. Surface protection (cleaning and painting)

3. Depreciation is the straight line allocation of total investment costs over the accounting life of the equipment

4. Other overhead for the control system includes:
   a. The cost of capital at 7% of the total investment cost
   b. Property taxes
   c. Insurance
   d. Miscellaneous

AFS Code____________

5. Process and equipment changes: include here changes in melting processes, melting equipment and furnace charge which were made when pollution control equipment was installed.

22. List and evaluate any benefits from controlling your air pollution such as reduced plant maintenance, reduced roof maintenance, increased property value, by-product recovery, reduced insurance premiums and fewer complaints by employees and neighbors, and/or problems incurred due to the control equipment such as design problems, start-up problems, and production delays.

AFS Code______________

23. Remarks.

(Coke Analysis)

REFERENCES

SECTION II

1. Foundry Magazine, "Foundry Census," July, 1970, pp. 94-95.

2. U.S. Dept. of Commerce, "Iron and Steel Foundries and Steel Ingot Producers, Summary for 1968," July, 1970.

3. Foundry Magazine, "Inventory of Foundry Equipment," 1968, 1960, 1954, 1957.

SECTION III

1. U.S. Department of Commerce News, Business and Defense Services Administration, BD 69-14, March 13, 1969.

2. The Cupola and Its Operation published by the American Foundrymen's Society, 3rd edition, 1965.

3. Metals Handbook: Volume 5 Forging and Casting, published by the American Society for Metals, 8th edition, 1970.

4. Principles of Metal Casting, R. Heine, McGraw-Hill Book Co., 1955, pp. 550-553.

SECTION IV

1. The Cupola and Its Operation, American Foundrymen's Society, Des Plaines, Illinois, 3rd edition, 1965

2. Kupolofenentstaubung, G. Engels and E. Weber, Giesserie-verlag G.m.b.H., Dusseldorf, translated by P. S. Cowen, Gray and Ductile Iron Founders' Society, Cleveland, Ohio.

3. "Reader's Comment. Letter from Institut fur Giessereitechnik," Dusseldorf, Germany, Foundry, December, 1969, p. 48.

4. Conference on Foundry Ventilation and Dust Control, Harrogate, England, 1965. British Cast Iron Research Association, Alvechurch, Birmingham.

5. Dust Collectors, American Foundrymen's Society, 1967.

6. Control of Emissions from Metal Melting Operations, American Foundrymen's Society, no date.

7. Cupola Dust Collection, W. Witheridge, The Foundry, March, 1950, p. 88.

8. Foundry Air Pollution Control Manual, American Foundrymen's Society, 1967.

9. Private communication.

10. Air Pollution Engineering Manual, U.S. Department of Health, Education and Welfare, Public Health Service, Publication No. 999-AP-40, 1967.

SECTION V

1. "Recommended Practice for Testing Particulate Emissions from Iron Foundry Cupolas," edited by a joint committee of American Foundrymen's Society and The Gray & Ductile Iron Founder's Society, Inc.

APPLICATION OF EMISSION CONTROL EQUIPMENT SYSTEMS TO FOUNDRY PROCESSES

Foundry Process	Dry Mechanical: Low Pressure Loss Cyclone	Dry Mechanical: Medium Pressure Loss	Wet Scrubber: Low Pressure Loss (Wet Cap)	Wet Scrubber: Medium Pressure Loss "4-8"	Wet Scrubber: Intermediate Pressure Loss "9-20"	Wet Scrubber: High Pressure Loss "21-80"	Fabric Filter: Cotton or Wool	Fabric Filter: Orlon or Dacron	Fabric Filter: Nomex	Fabric Filter: Glass	Electrostatic Precipitator: Dry	Electrostatic Precipitator: Wet	Catalytic Combustion
Raw Material Handling and Preparation	No	Rare	No	Rare	No	No	Rare	No	No	No	No	No	No
Melting Processes													
Cupola	Rare	Frequently	Frequently	Frequently	Frequently	Frequently	No	Rare	Occasionally	Frequently	Rare	No	No
Electric Arc	No	No	No	No	Rare	Occasionally	Rare	Usual	Rare	No	Rare	No	No
Electric Induction	No	No	No	No	No	No	No	No	No	No	No	No	No
Inoculation	No	No	No	Rare	Rare	Rare	Occasionally	Rare	Rare	No	No	No	No
Mold Pouring & Cooling	No	No	No	Rare	No	No	No	No	No	No	No	No	No
Shakeout													
Enclosed Hood	Rare	Occasionally	No	Usual	Occasionally	No	Occasionally	No	No	No	No	No	No
Side Hood	No	Rare	No	Usual	Occasionally	No	Occasionally	No	No	No	No	No	No
Sand Preparation & Handling													
Shakeout Molding Sand	Rare	Occasionally	No	Usual	Rare	No	Rare	No	No	No	No	No	No
New Sand	Rare	Occasionally	No	Usual	Rare	No	Occasionally	No	No	No	No	No	No
Core Sand	Rare	Occasionally	No	Usual	Rare	No	Occasionally	No	No	No	No	No	No
Coremaking													
Mechanical Material Handling	Rare	Rare	No	Frequently	No	No	Frequently	No	No	No	No	No	No
Pneumatic	No	No	No	Rare	No	No	Usual	No	No	No	No	No	No
Bake Oven	No	No	No	No	No	No	No	No	No	No	No	No	Frequently
Grinding	Rare	Occasionally	No	Frequently	No	No	Frequently	No	No	No	No	No	No
Casting Cleaning													
Airless Abrasive	No	Rare	No	Frequently	No	No	Usual	No	No	No	No	No	No
Blast Rooms	No	Rare	No	Usual	?	No	Usual	No	No	No	No	No	No
Tumbling Mills	No	Rare	No	Usual	?	No	Usual	No	No	No	No	No	No
Sprue	No	Occasionally	No	Usual	?	No	Usual	No	No	No	No	No	No
Grinding													
Snagging	Frequently	Frequently	No	Frequently	No	No	Frequently	No	No	No	No	No	No
Swing Frame	Rare	Frequently	No	Frequently	No	No	Frequently	No	No	No	No	No	No
Portable	Rare	Frequently	No	Usual	No	No	Usual	No	No	No	No	No	No
Boiler Fly Ash													
Chain Grate	No	Occasionally	No	No	No	No	No	No	No	No	No	No	No
Spreader Stoker	No	Usual	No	No	No	No	No	No	No	No	No	No	No
Pulverizer	No	Usual	No	No	No	No	No	No	No	No	Frequently	No	No
Paint Ovens	No	No	No	No	No	No	No	No	No	No	No	No	Frequently
Oil Burn-off Furnaces	No	No	No	Rare	No	No	No	No	No	No	No	No	Frequently
Pattern Shop													
Wood	Usual	Rare	No	Rare	No	No	Occasionally	No	No	No	No	No	No
Metal	Frequently	Usual	No	Rare	No	No	Occasionally	No	No	No	No	No	No

Sources: Foundry Air Pollution Control Manual, American Foundrymen's Society, 1967.
American Air Filter, Dust Collector Selection Guide, Bulletin 268-A, October, 1966.
Personal notes of John Kane.

SUMMARY STATISTICS - AIR POLLUTION CONTROL EQUIPMENT ON GRAY IRON FOUNDRY MELTING FURNACES
(Number of Foundries)

Group by Size (1967 Value of Gray Iron Shipments)	Type of Furnace				
	Cupola	Electric Arc	Electric Induction	Other	Total
Total respondent foundries	1,232	42	73	29	1,376
Under $500,000	525	20	34	25	604
$500,000 to $999,999	223	4	11	2	240
$1,000,000 to $2,499,999	221	10	16	-	247
$2,500,000 to $9,999,999	172	3	5	-	180
$10,000,000 and over	29	3	4	1	37
Value not reported	62	2	3	1	68
Total respondent foundries without furnace air pollution control equipment	1,052	18	73	29	1,172
Under $500,000	514	11	34	25	584
$500,000 to $999,999	200	-	11	2	213
$1,000,000 to $2,499,999	178	4	16	-	198
$2,500,000 to $9,999,999	107	-	5	-	112
$10,000,000 and over	7	1	4	1	13
Value not reported	46	2	3	1	52
Total respondent foundries with furnace air pollution control equipment	180	24	-	-	204
Under $500,000	11	9	-	-	20
$500,000 to $999,999	23	4	-	-	27
$1,000,000 to $2,499,999	43	6	-	-	49
$2,500,000 to $9,999,999	65	3	-	-	68
$10,000,000 and over	22	2	-	-	24
Value not reported	16	-	-	-	16
Type of equipment					
Wet Cap	95	-	-	-	95
Fabric filter	39	20	-	-	59
Particulate wet scrubber	30	4	-	-	34
Mechanical collector (Cyclone)	15	-	-	-	15
Electrostatic precipitator	1	-	-	-	1

SUMMARY STATISTICS - AIR POLLUTION CONTROL EQUIPMENT ON GRAY IRON FOUNDRY MELTING FURNACES
(Number of Foundries)

Group by Census Regions	Type of Furnace				
	Cupola	Electric Arc	Electric Induction	Other	Total
Total respondent foundries	1,232	42	73	29	1,376
New England	87	-	4	4	95
Middle Atlantic	229	4	11	3	247
East North Central	428	14	23	7	472
West North Central	115	2	2	2	121
South Atlantic	121	4	5	1	131
East South Central	100	2	5	1	108
West South Central	62	-	7	4	73
Mountain	18	2	6	1	27
Pacific	72	14	10	6	102
Total respondent foundries without furnace air pollution controls	1,052	18	73	29	1,172
New England	78	-	4	4	86
Middle Atlantic	207	-	11	3	221
East North Central	356	6	23	7	392
West North Central	103	1	2	2	108
South Atlantic	110	2	5	1	118
East South Central	88	1	5	1	95
West South Central	59	-	7	4	70
Mountain	15	1	6	1	23
Pacific	36	7	10	6	59
Total respondent foundries with furnace air pollution controls	180	24	-	-	204
New England	9	-	-	-	9
Middle Atlantic	22	4	-	-	26
East North Central	72	8	-	-	80
West North Central	12	1	-	-	13
South Atlantic	11	2	-	-	13
East South Central	12	1	-	-	13
West South Central	3	-	-	-	3
Mountain	3	1	-	-	4
Pacific	36	7	-	-	43

Source: Based on a survey conducted on BDSA Form 807--Gray Iron Foundry--Air Pollution Control.

COLLECTION EFFICIENCY OF EMISSION CONTROL EQUIPMENT SYSTEMS

Foundry Application	Particle Size	Typical Inlet Loading Gr/SCF	Typical Outlet Loading Gr/SCF: Wet Cap	Wet Scrubber 6"-30"	Wet Scrubber 30"-70"	Low Efficiency Cyclone	Fabric Filter	Electrostatic Precipitator
Melting								
Gray Iron Cupola	Coarse to Fine	1/2-10	0.4	0.3	0.05	0.4	0.01	0.036
Electric Arc	Fine	1/2-2	X	0.2	0.02	X	0.01	X
Screens and Transfer Points	Medium	1/2-3	X	0.005-0.01	X	X	0.01	X
Dry Sand Reclaimer	Coarse to Fine	10-40	X	0.1	0.02-0.05	X	0.01	X
Sand Cooler	Medium	1-20	X	0.01-0.05	X	X	X	X
Abrasive Cleaning	Fine to Coarse	1/2-5	X	0.01-0.05	X	X	0.01	X
Grinding	Coarse to Medium	1/2-2	X	0.01	X	0.1	0.01	X
Shakeout	Fine to Medium	1/2-1	X	0.01	X	X	X	X

Note: Particle Size

Coarse +20 Microns
Medium 2-20 Microns
Fine -2 Microns

X = Not applicable or rarely used.

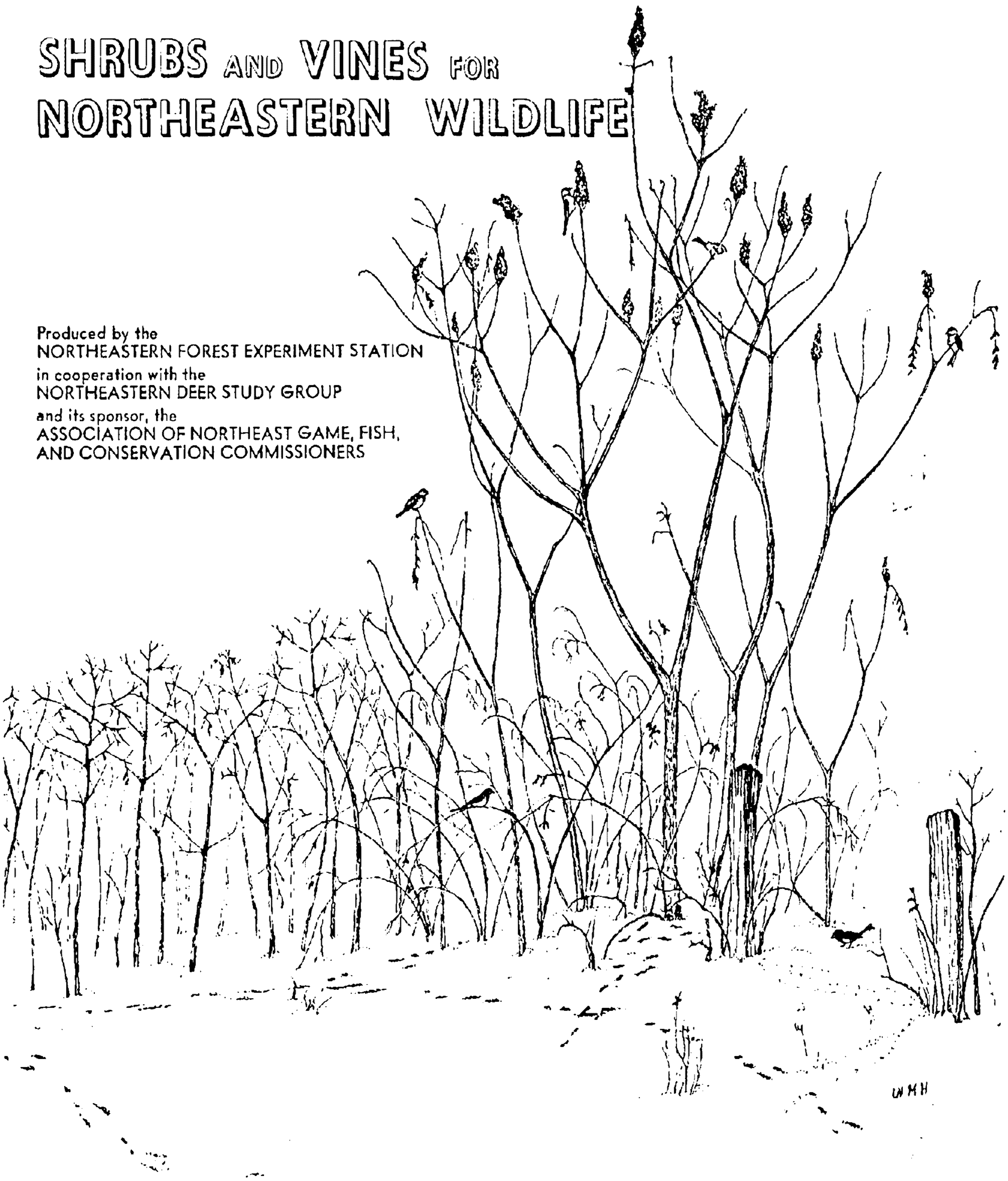
Underlined outlet loading is lowest for that application.

Sources: Foundry Air Pollution Control Manual, American Foundrymen's Society;
Air Pollution Engineering Manual, U.S. Department of Health, Education and Welfare, #999-AP-40.

EXHIBIT IV-19

NEFES / 77—2

SHRUBS AND VINES FOR NORTHEASTERN WILDLIFE



Produced by the
NORTHEASTERN FOREST EXPERIMENT STATION
in cooperation with the
NORTHEASTERN DEER STUDY GROUP
and its sponsor, the
ASSOCIATION OF NORTHEAST GAME, FISH, AND CONSERVATION COMMISSIONERS

USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-9
1974

ACKNOWLEDGMENTS

When the Northeastern Deer Study Group, sponsored by the Association of Northeast Game, Fish, and Conservation Commissioners, agreed to take on the job of producing this handbook, Chairman James S. Lindzey of the Pennsylvania Cooperative Wildlife Research Unit appointed Stephen A. Liscinsky of the Pennsylvania Game Commission and John D. Gill of the U.S. Forest Service to lead the project. They in turn called on Robert D. McDowell of the University of Connecticut, Earl F. Patric of the New York State University College of Forestry, and Ward M. Sharp of the USDI Bureau of Sport Fisheries and Wildlife for advice and review of plans.

Deer Study Group members in nearly all the northeastern states and provinces participated in selecting the species included in the report and in recruiting authors. At least 21 people functioned as key-men for individual areas or agencies. We cannot name all of them, but Joseph S. Larson of the University of Massachusetts and Stuart L. Free of the New York Department of Environmental Conservation were especially active in recruiting authors. When word of the handbook spread beyond the Northeast, we got additional help from Forest W. Stearns, then with the North Central Forest Experiment Station at Rhinelander, Wisconsin. Stearns' interest confirms that this handbook should be useful in the Great Lakes area as well as in the Northeast.

The work of most of the authors who are employed by state conservation departments and of several other biologists who are not specifically named here was supported by Federal Aid in Wildlife Restoration Funds. Francis B. Schuler of the USDI Bureau of Sport Fisheries and Wildlife at Boston has consistently encouraged the kind of cooperation among agencies that this handbook reflects.

So many other people helped that we do not have space to name all of them. But we must particularly thank Earl L. Core, who helped and encouraged us throughout this project.

—JOHN D. GILL and WILLIAM M. HEALY

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

BIBLIOGRAPHIC DATA SHEET	1. Report No. NEFES/7 7-2	2.	3. Recipient's Accession No.

4. Title and Subtitle

Shrubs and Vines for Northeastern Wildlife

5. Report Date April 1974 Publication date

6.

7. Author(s) Compiled and revised by John D. Gill, and William M. Healy

8. Performing Organization Rept. No. GTR-NE-9

9. Performing Organization Name and Address

Northeastern Forest Experiment Station
6816 Market Street
Upper Darby, Pa. 19082

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

Northeast Association of Fish and Wildlife Resource Agency
(No permanent address)

13. Type of Report & Period Covered

14.

15. Supplementary Notes

In cooperation with the Northeastern Deer Study Group

16. Abstracts

A non-technical handbook in which 34 authors discuss management of 97 native and 3 naturalized shrubs or woody vines most important to wildlife in the Northeast--Kentucky to Maryland to Newfoundland to Ontario. Topics include range, habitat, life history, uses, propagation, and management; but not identification.

17. Key Words and Document Analysis. 17a. Descriptors

Shrubs
Vines
Plant Ecology
Wildlife Management Habitat
Plant Management
Plant Culture

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement

Release Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages

SHRUBS AND VINES FOR NORTHEASTERN WILDLIFE

Compiled and revised by

JOHN D. GILL and WILLIAM M. HEALY

JOHN D. GILL leads the Northeastern Forest Experiment Station's wildlife-habitat research project at the Forestry Sciences Laboratory, 180 Canfield Street, Morgantown, West Virginia 26505, in cooperation with West Virginia University. Gill is a member of the University's graduate faculty in the Division of Forestry. He joined the Forest Service in 1967 after service in the Maine Department of Inland Fisheries and Game (Orono, 1955 to 1967) and the West Virginia Conservation Commission (Elkins, 1950 to 1955). While attending Michigan State University (1947 to 1950) he worked part-time for the Michigan Game Division.

WILLIAM M. HEALY, associate research wildlife biologist, has worked with Gill since completing master's degree studies at the Pennsylvania State University in 1967. His research mostly concerns habitat requirements of wild turkeys. He also holds the rank of instructor in the West Virginia University Division of Forestry and is working toward a Ph.D. degree in animal behavior.

MANUSCRIPT RECEIVED FOR PUBLICATION 12 MARCH 1973

CONTENTS

A HANDBOOK ON SHRUBS AND VINES

By John D. Gill and William M. Healy

USDA Forest Service
Northeastern Forest Experiment Station
Forestry Sciences Laboratory
Morgantown, West Virginia

This handbook was prepared to provide practical information about managing the shrubs and woody vines of the Northeast that are important to wild birds and mammals for food and protective cover.

This work stemmed from forest-wildlife research needs expressed in a series of analyses begun within the Northeast Section of The Wildlife Society and later sponsored by the Association of Northeast Game, Fish, and Conservation Commissioners. A committee organized by federal-aid supervisors in the USDI Bureau of Sport Fisheries and Wildlife at Boston recommended preparation of a handbook to pull together available information that would be useful in the management of shrubs and vines for wildlife. The committee noted that, though several recently published handbooks provided information about commercially valuable tree species, no such handbook was available for the smaller woody plants.

Work on the handbook began in 1967 when the Northeastern Deer Study Group, sponsored by the Commissioners, agreed to take on the job.

As the first step in planning the handbook, we listed nearly all the shrubs and woody vines that had been reported to have some kind of value for wildlife. Then biologists throughout the Northeast were asked to review the list and rate the plants to help us select the most important species to include.

The selected list includes plants in 36 genera and 100 species. Besides the native plants, we included three exotics that have become widely naturalized: a rose and two honeysuckles.

There may be some bias in the selection, because most of the wildlife biologists who participated in selecting the plants had been working almost exclusively with game species, and many were specialists on deer. However, we feel that this bias is not serious, because many groups of game animals and non-game animals have similar habitat requirements.

We made no attempt to illustrate the plants for purposes of identification. Illustrated field guides to woody plants are readily available, as are state and provincial flora publications.

The handbook contains 41 chapters by different authors. To avoid repetition, literature references have been consolidated into a single list at the back of the book. A glossary of terms is also appended.

The authors hope that this handbook will prove useful not only to wildlife managers, but also to anyone who owns or manages land or is interested in providing favorable habitat for wildlife.

ECOLOGY OF SHRUBS AND VINES

By Ward M. Sharp
Bureau of Sport Fisheries and Wildlife
Warren, Pennsylvania

The ecology of shrubs and woody vines concerns the interactions among shrubs and vines, other plants, animals, and the environment. As examples, interactions of shrubs with other plants and with fire have an impact on the welfare and development of shrubs in the landscape. Animals play a key role, exerting both beneficial and detrimental effects.

Shrubs cannot be defined exactly. Generally, they are low, erect, woody plants, usually under 25 feet in height, and usually have several stems. Any definition is arbitrary because of the great variation in height and form. The person who is not familiar with either trees or erect shrubs may encounter difficulty in distinguishing tree regeneration or small trees from shrubs.

GROWTH FORMS

Individual species fall into one, or in some cases more than one, of the following categories: (1) erect shrubs, either clonal, multistemmed, or single-stemmed; and (2) climbing or trailing shrubs or vines.

Clonal shrubs and vines form dense colonies from underground, horizontal rootstocks. Colonies may develop from a single seedling. Smooth sumac (*Rhus glabra*) grown from seed will start clonal development by the fifth year. Other plants of clonal habit, for example, are lowbush blueberries (*Vaccinium* spp.), gray-stemmed dogwood (*Cornus racemosa*), blackberries (*Rubus* spp.), and the low serviceberries (*Amelanchier* spp.). In optimal sites American elder (*Sambucus canadensis*) may become clonal. Fire stimulates seed germination in all clonal species, and some species such as lowbush blueberries need to be burned on a rotation basis.

The multi-stemmed shrubs include those that produce numerous stems from a common root collar. Typical examples are the highbush blueberries, witherod (*Viburnum cassinoides*), and mountain laurel (*Kalmia latifolia*).

Single-stemmed shrubs include many of the tall species. Shrubs in this group grow from a single stem, or sometimes two or more stems may originate from near ground level. Flowering dogwood (*Cornus florida*), hawthorns (*Crataegus* spp.), and hophornbeam (*Ostrya virginiana*) belong in this category.

Climbing or trailing woody shrubs or vines are ecologically similar to erect shrubs, although in appearance the relationship may seem remote. The vine growth form may hold for all species of a genus such as grape (*Vitis*) or greenbrier (*Smilax*), but not for all species of genera such as honeysuckle (*Lonicera*) or bramble (*Rubus*).

The climbing vines often use erect shrubs or trees for support and access to sunlight. Woody vines, like wild grape, usually become established at the same time as new tree and shrub regeneration. Once established, they grow along with their supporting plants. They seldom take hold in forest stands once the trees attain pole-timber size. Trailing vines such as dewberries (*Rubus* spp.) usually grow in open fields. They compete for sunlight with grasses and forbs by trailing over the herbaceous plants.

ENVIRONMENTAL FACTORS

The principal factors that interact on shrubs are (1) physical--sunlight, soils and moisture, temperature, and fire; and (2) biological—browsing, insects and disease, and seed dispersal by animals.

Sunlight

Among all the environmental factors, full sunlight is most important for nearly all species. When luxuriant shrubs are shaded by the dense canopy of invading trees, most species become suppressed and wane regardless of other factors such as moisture, temperature, and soil nutrients. When taller shrubs are shaded after they reach normal height, they may persist longer than the low-growing species. Those that persist are suppressed. Their vigor wanes and their fruiting potential declines.

There are exceptions to this, however. A few species grow well in partial or full shade. But the majority grow best and produce the most fruit in openings such as road edges, old fields, and clearcut forest stands.

From the importance of full sunlight in the life span of most shrub communities, one may reason that shrubs evolved in a grassland or a forb-grass environment. They transformed these sites into savannas that later were invaded by trees. Man and fire have played leading roles in perpetuating sunlight exposure in the shrub community.

Soils and Moisture

Soil and moisture are combined here because shrubs tolerate a wide range of soil and moisture conditions. Some shrubs occur in wet sites while others need dry upland sites. This requirement varies even among species of the same genus, such as blueberries. Lowbush blueberries require dry upland soils; native highbush blueberries establish best in wet soils or soils that are waterlogged in spring.

Some shrubs prefer soils of limestone origin; others prefer acid soils of sandstone origin; and others are tolerant of a wide range of soil and moisture conditions. This trait also varies among species within a genus such as serviceberry, dogwood, and hawthorn. The shrubby roundleaf serviceberry (*A. sanguinea*) occurs in Pennsylvania on limestone soils, while downy serviceberry (*A. arborea*) is common throughout the state.

It is pointless to try to lay down hard and fast rules on the soil and moisture requirements of shrubs and vines in general. These needs are as variable as the needs among tree species.

Temperature

Temperature is most important during flowering and setting of the fruit crop. When temperatures drop below freezing during flowering, the entire fruit crop may be eliminated. In other respects, native shrubs in the region are adapted to temperature extremes in winter.

Fire

Fire has been a key factor in the shrub community for so long that many species evolved through periodic occurrence of fire. Consequently, many shrubs are fire-adapted. The known fire-adapted species are those that form clonal colonies from a horizontal root system. Many of the multi-stem groups benefit from the influence of periodic burning. Shrubs of the heath family such a blueberries, huckleberries, and mountain laurel are rejuvenated by periodic burning.

Fire serves four roles in shrub management. It is a pruning and sanitation agent for cleaning up dead or decadent stems; it tends to set back tree regeneration; it is conducive to breaking seed dormancy and stimulating germination; and it helps control disease and insects.

For fire to serve best, it must be used periodically and in a prescribed manner. Except for lowbush blueberries, the optimum intervals between burnings have not been resolved. Prescriptions should give season, moisture conditions, and the method under which fire is used. Optimal benefits are usually derived from burning in early spring. Burning in droughty periods or after leaves have unfolded may be more detrimental than beneficial. The beneficial role of fire in shrub management is neither widely recognized nor practiced in wildlife management.

Browsing

The impact of browsing on shrub or vine species depends largely on their palatability to browsing animals. mainly deer, rabbits, rodents, and livestock. Most shrubs are vulnerable only at a particular stage in their life cycle, such as the seedling and early regeneration stages.

The tops of some clonal and multi-stem shrubs never grow beyond the reach of browsing mammals. Therefore these shrubs have developed growth qualities that resist browsing. Crowns of low hawthorns, for example, become hedged from browsing; and the thorny, hedged crowns prevent overbrowsing. Inhibiting substances which render some shrubs unpalatable are known. Mountain laurel is toxic to some hoofed animals, especially sheep; and elderberries are unpalatable to cattle.

The effects of browsing by deer may vary because of changes in factors other than the browsing itself. For example, Pennsylvania had a lage deer herd in 1930 to 1960. In that period, a closed-canopy poletimber forest also developed. Such shrubs as mountain laurel and the scrub oaks--lightly browsed by deer and intolerant to shading—died beneath the closed canopy of trees. Therefore all factors of the shrub environment must be evaluated before damage is attributed exclusively to deer.

Cottontails and woodchucks prefer seeding shrubs under 24 inches in height. In my attempts to propagate American elder in wildlife areas, woodchucks and cottontails were as destructive as deer. Mice girdle shrubs at ground level; consequently, their damage may go undetected.

Insects and Diseases

The detrimental impact of insects and fungous diseases may be greater than that of browsing mammals. This impact may be local, it may go undetected, or it may be more prevalent among certain groups of shrubs than among others.

Insects are principally defoliators, but some attack the succulent shoot tips or the woody branches. Defoliators are periodic as a rule, but complete defoliation even for one season can trigger a decline in shrub vigor. I have observed that defoliation in a colony of gray dogwood was followed by failure to set fruit in the following years and by top dieback. Sucking insects such as lace bugs and aphids may destroy the leaf chlorophyll, leaving the foliage with a seared to brownish appearance by August. Aphid attacks on succulent shoot tips in seedling shrubs can weaken plants so that they succumb to winter-kill or drought.

The fungous diseases most frequently encountered among shrubs are those that attack the flowers, fruits, leaves, and stems. Those attacking the rootstocks are little known except by pathologists and may go undetected. Rust, leaf spot, and mildew are the diseases most frequently observed.

Many of the fungi may affect the flowers and fruits, thus reducing fruit quality and yield. Affected fruits either drop prematurely or those that persist are deformed or mummified (*Heald 1926*). Fruits of wild grapes are commonly mummified by fungous diseases. Rust diseases may be fatal. For example, hawthorn rust is often fatal where the alternate host, eastern redcedar (*Juniperus virginiana*), is common. Leaf spot diseases kill parts of the leaves, thus reducing photosynthetic activity. They also affect the flowers and fruits. The impact of disease on shrubs results in unthrifty or undernourished plants or total kill.

Prescribed or controlled burning in shrub communities will help control fungous diseases, such as leaf spot, and some defoliating insects. But rust control is realized only by removal of the alternate host. Fungicidal sprays are not considered economically feasible for native shrubs. Spraying insecticides for leaf defoliators is also impractical in managing shrubs in a unit of wildlife range.

Seed Dispersal by Animals

Shrubs and vines that produce berries or fleshy fruits depend on birds and mammals for seed dispersal. Seeds of these fruits are mostly small with hard seedcoats; and when eaten by most birds and some mammals, they are passed through the digestive tract either unharmed or treated so as to increase germinative capacity (*Krefting and Roe 1949*).

Birds are more efficient disseminators than mammals. In bird droppings, seeds are more widely dispersed, and fewer seeds are deposited at one site. Mammals such as raccoons and foxes deposit numerous seeds at a spot.

But birds and mammals may destroy those seeds that have a large endosperm, such as hazelnuts (*Corylus* spp.), scrub oak acorns (*Quercus ilicifolia*), or chokecherry (*Prunus virginiana*). Small rodents, in particular, consume the embryo along with the endosperm.

LAND USE

The era of native shrubs and vines probably reached its peak between 1900 and 1920 in the Middle Atlantic and Northeastern States. Up to that time, vast acreages had been converted to farm and pastureland. Livestock production equalled that of row crops. Lumbering operations had converted extensive areas to brushland. Use of fire in the landscape was a common and accepted practice. The period before 1920 was the agricultural era in the region.

Farm and pasture abandonment was characteristic of the decades after 1920. Beginning about 1933, fence rows between fields were being eliminated in a move toward clean farming. Land in farms and pastures in New York, for example, totalled 22,600,795 acres in 1910, but by 1950 farm abandonment had reduced this area by 40 percent to 13,672,937 acres (*Conklin 1954*). A similar or even greater abandonment of farm and pasture land since 1910 or earlier has occurred in most northeastern states. (*Frey et al. 1957*). The trend is continuing.

It has not been generally realized that in the agricultural era, conditions of rural living (including clearing and burning, extensive acres of pastureland, fence rows, and early lumbering operations) enabled native shrubs to flourish and increase in abundance. Now, with clean farming, use of herbicides, and conversion of abandoned farms to a closed-canopy forest, native shrubs have declined in sites where they were formerly abundant. These conditions point up the need for an aroused interest in the ecology and management of native shrubs and vines.

Beginning in the 1930s, shrubs from other parts of the world took precedence over native species. Much emphasis has been placed on exotic species for wildlife and soil-erosion plantings since that time. Consequently, native species received little study except by a few individuals who recognized the limitations and risks of exotics compared to native species. Even with the emphasis on planting millions of exotics in wildlife habitats, they have contributed little forage or fruits for wildlife. Having conducted studies in shrub ecology over the past two decades in Pennsylvania, I can only view the future with concern if interest in native shrubs continues to lag as in the past four decades.

ALDERS

SPECKLED ALDER, *Alnus rugosa* (Du Roi) Spreng. Also called Hoary or Tag Alder.

HAZEL ALDER, *Alnus Serrulata* (Ait.) Willd. Also called Common, Smooth, and Streambank Alder.

By William M. Healy and John D. Gill

Northeastern Forest Experiment Station
Morgantown, West Virginia

RANGE

The combined ranges of the two species include the entire region. Speckled alder occurs from Newfoundland to British Columbia and southward to Maryland, West Virginia, Ohio, northern Indiana, and Minnesota. Hazel alder grows as far north as Maine and ranges southward to Florida and Texas (*Gleason 1963b*).

HABITAT

Speckled alder is the more northern species. It is most common along the northern boundary of the United States (*Brickman 1950*) and is restricted to higher elevations at the southern edge of its range. In West Virginia, hazel alder grows mostly at elevations below 2,600 feet, while speckled alder is common in the mountains above 2,600 feet (*Strausbaugh and Core 1952-64*). Optimum growing conditions for the alders have not been described, but it is possible that climatic factors limit both species at the edges of their ranges.

Alders most commonly occupy poorly drained soils. Typically, they border streambanks and form thickets where surface drainage is slow and the ground-water level is near the surface during part of the growing season. Saturated soil appears to be required for seed germination.

One study showed that saturation for intervals of 1 to 16 days stimulated growth of newly emerged hazel alder seedlings (*McDermott 1954*). In a study in northern Michigan, Brickman (*1950*) found speckled alder growing only on sites that had a saturated soil during the spring months, although some alder sites became dry during late summer. From this and other observations, he felt that speckled alder requires a saturated soil on which to germinate and become established.

Speckled alder grows well on a variety of soils, including rocky till, sandy loam, gray forest soils, and muck. The range of tolerance to alkalinity or acidity could not be found, but is probably similar to that of European alder (*A. glutinosa* [L.] Gaertn.) and European speckled alder (*A. incana* [L.] Moench.), which grew well on Ohio spoil banks with a pH range of 3.4 to 7.7 (*Lowry et al 1967*).

In the oak-hickory region, flood plains commonly support stands of alders and willows; if undisturbed, these shrubs give way to American sycamore, elms, red maple, and sweetgum.

In northern forests, alders grow with willows and heath shrubs as well as tamarack, birches, aspens, and conifers (*Shelford 1963*).

About 80 species of plants were found growing in hazel alder stands in Pennsylvania, but silky dogwood, black willow, jewelweed (*Impatiens* spp.), and sensitive fern (*Onoclea sensibilis*) were the most characteristic (*Liscinsky 1972:35*). Blackberries, common chokeberry, American elm, goldenrod (*Solidago* spp.), bluegrass (*Poa* spp.), and asters (*Aster* spp.) were also common associates (*Liscinsky 1972:35*).

LIFE HISTORY

Individual alders bear male and female flowers on separate catkins. Flowering occurs in April-May on catkins formed during the preceding year (*Basset et al 1961*). Wind spreads the pollen. The seed matures in egg-shaped conelets. Seed occasionally ripens as early as August and is usually fully ripe by September or October (*U. S. Forest Service 1948*).

No information about the youngest or oldest seed-bearing age in speckled alder was found, and little is known about geographical differences in seed production. Other alder species bear seed when less than 10 years old and yield good seed crops almost every year. Winds spread the seeds during September through April. Spreading distances and the number of seeds produced per plant are not definitely known.

Alders reproduce from seeds, sprouts, layering, underground stems, and suckers. Seed is the primary source of new stands on freshly exposed soil. Perpetuation and spread of established stands result mostly from sprouting or other vegetative means.

Growth rates depend on many factors, including site conditions, competition, and type of growth (seedling or sprout). The largest speckled alder stand observed in a Michigan study was 26 years old and had stems averaging 5.5 inches d.b.h. and 25 feet tall (*Brickman 1950*). Clearcutting one aspen-balsam poplar-speckled alder stand in northern Michigan resulted in a dense stand of alder sprouts, which reached a maximum height of 6 feet the second year after cutting (*Day 1956*). Eight speckled alder stands in Ontario showed great variation in height/age relationships among individual stems. The alder stands were growing on peat-covered clay soils and had originated after clearcutting black spruce. The tallest stem measured was 12 feet high and 13 years old, while the oldest was 30 years old and only 5.5 feet high. The average height of the speckled alder canopy varied from 3 to 6 feet, and the annual height growth declined steadily after 9 to 10 years of age (*Vincent 1964*).

Hazel alder stands in Pennsylvania had similar growth patterns. Stem growth was most vigorous from 1 to 8 years. Stems were more than 15 feet tall at 10 years of age, but height increased little during the next 10 years. After about 20 years of age, many stems began to die and few stems reached 30 years of age (*Liscinsky 1972:36*).

The alders are primary invaders of denuded areas with saturated soil. Both species grow more vigorously in full sunlight than in shade, and they are intolerant to intermediate in tolerance to shading. In general, sprouts are more tolerant of shade than seedlings (*Brickman 1950*) and speckled alder may be more tolerant than hazel alder.

Hazel alder stands in Pennsylvania seldom regenerate themselves, and they are usually replaced by trees (*Liscinsky 1972*). Speckled alder stands in northern Michigan are often overtopped by species such as balsam fir, northern white-cedar, and red maple, but it takes many years for these species to replace alder (*Brickman 1950*). In the same area, speckled alder is common beneath stands of tamarack, balsam poplar, aspen, and birch; and on some sites it may even replace aspen and balsam poplar (*Brickman 1950*). Speckled alder has been recommended for ornamental plantings in shady areas (*Kammerer 1934*).

USE BY WILDLIFE

Moose, muskrats, beavers, cottontails, and snowshoe hares feed on twigs and foliage. Deer browse alders, but most investigators rate the plant low in preference. Woodcock and grouse eat small quantities of buds, catkins, and seeds. Alder seeds are also eaten by some smaller birds, particularly redpolls and, to a lesser extent, goldfinches (*Martin et al 1951*).

Alder is an important cover plant for woodcock and grouse. Woodcock use alder covers from early spring through fall for nesting, feeding, and resting. They prefer the edges more than centers of large evenage thickets (*Liscinsky 1965*). Alder stands were considered important grouse cover in Michigan, particularly where deer had eliminated other shrubs. Speckled alder provided the high shrub cover needed around grouse drumming sites (*Palmer 1963*). Beavers commonly use alders in dam construction.

PROPAGATION

It is usually best to collect and process local shrubs. Seed or seedling stock is seldom available commercially. Conelets can be harvested in September and October from standing or felled alders. Seeds are easily shaken out of dried conelets, but it is difficult to fan or screen out impurities (*U.S. Forest Service 1948*).

The following information pertains to hazel alder seeds gathered in Pennsylvania (*Liscinsky 1972:63*). When seed was plentiful it took 1 hour to pick 4 gallons of cones, which produced 1.6 pounds of seed (3.2 quarts). When seed was scarce, it took 1 hour to pick 1 gallon of cones, which yielded 0.4 pounds of seed. It took 2.5 gallons of cones to produce 1 pound of seed. Purity of seed ranged from 60 to 90 percent, and soundness ranged from 30 to 60 percent. Germination capacity varied from 2 to 60 percent. One pound of seed had a volume of 2 quarts and contained a total of 300,000 seeds.

The number of speckled alder seeds per pound is variable. Separate studies yield the ranges of 256,000 to 625,000 (*Van Dersal 1938*) and 473,000 to 890,000 (*U. S. Forest Service 1948*) seeds per pound. The latter group averaged 666,000 seeds per pound, 41 percent pure and 51 percent sound (*U. S. Forest Service 1948*). Yields of usable plants per pound of seed have been reported as 10,000 for speckled alder and 40,000 for hazel alder (*Van Dersal 1938*).

The easiest way to handle alder in the nursery is to sow fresh clean seed in November (*Heit 1968:15*). Seed should be broadcast or drilled in and lightly covered with either washed sand or sand mixed with hardwood humus. Either was superior to nursery soil or leaf litter for covering speckled alder seedbeds (*U. S. Forest Service 1948*). Seedbeds should be mulched for overwinter protection, but the mulch should be removed when germination begins in the spring. The beds should be kept moist and shaded until late summer of the first season (*U. S. Forest Service 1948*).

Seed may be planted in the spring if it is first stratified in moist sand or vermiculite for 60 to 90 days. Speckled alder seeds stratified for 2 months at 32 to 40° F. gave excellent germination within 10 days after sowing (*Daly 1966*). Hazel alder seeds stored at 41°F. for 206 days gave 30 percent germination, which was mostly complete 10 days after sowing. Keeping the seeds in complete darkness had no effect on percent or time of germination (*McDermott 1953*).

For long-term storage, seeds should be thoroughly cleaned, air-dried and refrigerated in sealed containers. Alder seeds kept in this manner at 34 to 38°F. were viable after 10 years (*Heit 1967e*).

Two- and 3-year-old seedlings should be used for field plantings; 1-year-old hazel alder stock had very low average survival in the field (*Liscinsky 1972:61*). Plantings succeeded on a variety of sites, but not on extremely dry soil. Heavy sod should be scalped back before planting; competition from dense herbaceous vegetation can cause planting failures.

Direct seeding of hazel alder in the field has been successful in Pennsylvania (*Liscinsky 1965, 1972*). Seedbeds prepared by disking produced 35 percent more seedlings than untreated plots, but good catches occurred even when seed was sown directly on sod. Cool, moist sites were best for direct seeding, and the sites closest to the stream produced the most seedlings. Generally, the best results were obtained when fall-collected seed was sown during the following February and March. Seeding rates were about ½ pint (⅛ pound) per 100 square feet. Attempts to propagate hazel alder in the field from stem and root cuttings were unsuccessful (*Liscinsky 1972:61*).

MANAGEMENT

Alders, along with other desirable species, are good for reforesting various kinds of spoil banks. Alders are also ideal as streambank cover and for increasing the fertility of bottomlands. Fertility increase is from nitrogen-fixation by root nodules and from fallen leaves. The amount of nitrogen added to the soil varies, but in general the alders compare favorably with legume crops and black locust (*Daly 1966, Lawrence 1958, Lowry et al 1967*). European foresters plant alders beneath conifers to increase soil nitrogen and stimulate the growth of crop trees.

Alder stands can be established by planting seedlings or by direct-seeding on cool, moist sites. Where alders are present but suppressed, fire and most logging practices favor alder over competing species. Large stands of alders commonly form after spruce and fir are logged from wet ground.

Large stands are probably best managed for wildlife on a rotation of 30 years or less, based on the time the alders require to reach maturity or grow so tall that they handicap hunters. Cutting schemes should provide patches of various age classes, well dispersed throughout the stand. A cutting cycle of approximately 25 years, with cutting at 4- to 5-year intervals, has been recommended for managing alder coverts for woodcock in Pennsylvania (*Liscinsky 1972*).

Overmature thickets can be opened up by clearcutting. Spring and winter cutting will result in the most rapid sprout growth; July and August cutting will produce the thinnest stands and least height growth (*Brickman 1950*). Stands overtopped by larger trees respond well to release cutting, but stumps of pole-size hardwoods should be poisoned to reduce sprouting. Competition from tree seedlings, particularly conifers, should not limit stump sprouting of alders.

Several formulations of the herbicides 2,4,5-T and 2,4-D effectively control alders when applied as stump, basal, or foliage sprays (*Liscinsky, personal communication*).

AMERICAN BITTERSWEET

Celastrus scandens L.

Also called Climbing, False, or Shrubby Bittersweet; and Waxwork.

By Jack I. Cromer

West Virginia Department of Natural Resources
Elkins

RANGE

American bittersweet occurs from southern Quebec to southern Manitoba and southward to Georgia, Alabama, Louisiana, Oklahoma, Texas, and New Mexico.

HABITAT

This vine grows under a diversity of climatic conditions, but no information about climatic optima or limits was found.

It is common along stream banks, in old fields, in low thickets, and in fencerows. It tolerates a variety of soil textures (sand, loam, and clay), but prefers soils with a nearly neutral pH (*Wherry 1957*). It grows well in partial shade or full sunlight, but best in sunny locations, either on banks or where the vines can ascend a supporting structure (*Holweg 1964, Hosley 1938*).

Associated plants in Minnesota were moonseed (*Menispermum canadense*), frost grape (*Vitis* spp.), and prickly ash (*Xanthoxylum americanum*) (*Daubenmire 1936*); and in Missouri redbud (*Cercis canadensis*), herbaceous mandrake (*Podophyllum peltatum*), goosegrass (*Eleusine indica*), and Miami-mist (*Phacelia purshii*) (*Shelford 1963*).

LIFE HISTORY

Greenish-yellow flowers appear in late May and June. On individual plants, flowers are mostly unisexual. The primarily female-flower plants usually have enough male flowers for fertilization (*Hosley 1938*), but plants of both sexes should be fairly close together to insure good fruiting (*Holweg 1964*). Fruits ripen in September and October; some may persist on the plants as late as March, although most drop before late winter (*Petrides 1942*).

Seed production starts at 3 years in vigorous plants growing in full sunlight (*Spinner and Ostrom 1945*), but may be delayed a year or longer in less vigorous plants. Good seed crops are commonly produced each year.

Bittersweet may reproduce by layering or from stolons.

Growth rate of plantings is variable; in Vermont, Delaware, and West Virginia, average lengths of 7-year-old stems ranged from 15 inches to 12 feet. Generally, stem growth averaged 12 to 30 inches in 3 years, 30 to 60 inches in 5 years, and about 6 feet in 7 years, with little additional growth afterwards (*Edminster and May 1951*).

On good sites, bittersweet is aggressive and competes well with other vegetation. However, plantings along pasture fences are commonly browsed back to stubs whenever they are within reach of cattle (*Edminster and May 1951*). Plantings in New York were also retarded by browsing deer (*Smith 1962*) and rabbits (*Petrides 1942*).

USE BY WILDLIFE

Fruits, buds, and leaves are potential food for ruffed grouse, pheasants, quail, wild turkeys, and other birds. Rabbits and squirrels relish the fruits; rabbits and deer eat the leaves and stems.

The twining vines form excellent wildlife cover. Bittersweet, along with wild grape and elderberry, provides outstandingly acceptable nesting sites for hedgerow birds (*Petrides 1942*).

PROPAGATION

Bittersweet can be propagated easily from cuttings of mature shoots, layerings, or roots (*Fuller 1910*). Female plants are preferred as stock. Root cuttings, either softwood in summer or hardwood in fall and winter, have been used successfully (*Hosely 1938*).

Seeds can be collected in mid-September and later, as long as the fruit capsules hang on. They should be spread out and allowed to air-dry for 2 or 3 weeks. Cleaned seeds average 26,000 per pound (12,000 to 40,000). Average purity of commercial seed was 93 to 98 percent and soundness was about 84 percent (*U. S. Forest Service 1948*).

Seed dormancy is broken by pre-chilling for 2 to 6 months. Stratification in moist sand or peat for 90 days at 41°F. is recommended (*Barton 1939*). Seeds stored in a cool-damp basement gave no germination after 1 year, but seeds that had been air-dried and stored in sealed glass containers at 34 to 38°F. retained excellent germination capacity after 4 to 8 years (*Heit 1967e*).

If stratification is impractical, seeds can be sown in the fall; however, emerging seedlings are susceptible to decay by soil-inhabiting fungi. For outplanting, 2-year-old seedlings are apparently best. At each planting site, all competing vegetation should be removed from at least 1 square foot (*Edminster and May 1951*) around the plant.

MANAGEMENT

Aside from having food and cover value for wildlife, bittersweet is a desirable ornamental and can also be used to control erosion. The fall leaf color is yellow, and the persistent orange fruits add attractive color to landscapes during fall and early winter. This species is especially well adapted for training over outbuildings and for climbing over walls, trellises, trees, and shrubs (*Hosley 1938*).

Plantings have generally survived well, and they spread by runners; but growth and fruit production have often been retarded by rabbit and deer browsing (*Smith 1962*). The high palatability of this plant requires caution in selection of planting sites. The best use of bittersweet may be as a filler among plantings or natural growths of other shrub species (*Edminster and May 1951*).

Aggressiveness of bittersweet should also be considered, because rapid spread on exceptionally favorable sites may lead to control problems. No specific information about control methods was found.

MISCELLANY

The fruiting branches are valuable for commercial use or as home decorations; however, bittersweet fruits are thought to be poisonous if eaten by humans (*Grimm 1952*).

BLUEBERRIES

LOWBUSH BLUEBERRY, *Vaccinium angustifolium* Ait. Also called Lowsweet, Dwarf or Sugar Blueberry, Sweethurts, and Strawberry-Huckleberry.

HIGHBUSH BLUEBERRY, *Vaccinium corymbosum* L. Also called Tall or Swamp Blueberry, Wortleberry, and Seedy Dewberry.

By Robert Rogers

Rutgers University
The State University of New Jersey
New Brunswick

RANGE

Lowbush blueberry, the more northerly species, occurs from the tundra in Canada, throughout the New England States, in the Piedmont and mountain areas of Pennsylvania and New Jersey, and south down the Appalachian Mountains to northern Virginia (*Darrow and Moore 1966*). Highbush blueberry occurs along the Atlantic Coast from eastern Maine to northern Florida and also in the Great Lakes region, including northern Indiana, northern Ohio, northwestern Pennsylvania, southern Wisconsin, and southern Ontario (*Darrow and Moore 1966*).

HABITAT

Both species are acclimated to climatic extremes in the southern part of the region. In the northern part of the region, growth of highbush blueberry is limited by growing season and extreme winter temperatures. A minimum adequate growing season of 160 days is required for highbush blueberry (*Chandler 1943*). Temperatures below −20°F result in winter-kill, and temperatures below 30°F will kill plants to ground or snow level (*Cain and Slate 1953*). Although lowbush blueberries border the tundra in Canada, they are favored by a minimum growing season of 125 days (*Chandler 1943*). Lowbush blueberry is found farther north than highbush blueberry, perhaps because its prostrate form accommodates it to a protective snow cover (*Eaton 1949*). Summer temperatures in excess of 120°F can cause mortality in young plants (*Kender and Brightwell 1966*).

Blueberries, like most members of the Heath family, prefer acid soil. They make their best growth on light, well-drained acidic soils high in organic-matter content (*Kender and Brightwell 1966, Van Dersal 1938*). Soils developed from limestone are not conducive to good blueberry growth.

Lowbush blueberry is the typical upland blueberry in the Appalachian Mountain areas from West Virginia north to the New England States. Stony, silt, and clay loam soils developed from sandstones, shales, and glacial drift commonly support colonies of lowbush blueberry. These colonies often occur on dry, rocky, open upper slopes and ridgetops (*Braun 1950, Fernald 1950, Darrow and Moore 1966, Van Dersal 1938*).

Highbush blueberry is frequently found at lower elevations along the Atlantic Coast and in the Great Lakes region, where it occurs along the edges of swamps, within open areas of moist woodlands, and occasionally in moist upland fields (*Fernald 1950, Darrow and Moore 1966*). Highbush blueberries grow: on soils consisting of sandy loams developed on Coastal Plain sands and clays in Maryland, Delaware, southern New Jersey, Long Island, and southeastern Massachusetts; sands and loamy sands developed on glacial drift; and on stony and gravely silt and clay loams developed on glacial drift, which frequently have a hardpan in the soil profile (*Beckwith and Coville 1931, Johnston 1942, Trevett 1962, Van Dersal 1938*).

Heavy soils with poor drainage prevent root penetration and thereby increase the probability of frost heaving; and coarse sandy soils present droughty conditions during summer months despite normal rainfall. During dry periods, blueberries are hindered in water uptake because they lack root hairs (*Ballinger 1966, Kender and Brightwell 1966*). Optimum growth of blueberry occurs when soil pH is between 4.3 and 4.8 (*Kender and Brightwell 1966*). However, blueberries are commonly found on soils having pH values ranging from 3.5 to 5.5, although soil pH values higher than 5.2 seem to limit growth (*Ballinger 1966*).

Blueberries are relatively intolerant to shade, and tend to flourish in open areas. Shading reduces vegetative growth and flower-bud formation in both species (*Hall 1958, Reiners 1967*). Throughout the region, both species are found in association with other members of the Heath family, especially mountain laurel, huckleberry, and azalea. On moist sites along the Atlantic Coast, highbush blueberry may grow with alder, gray birch, blackhaw, arrowood, silky dogwood, and red and black chokeberry. It may be succeeded by red maple, blackgum, ash, sweetgum, elm, yellow-poplar, pin oak, white oak, black oak, and shagbark and mockernut hickories. The chief shrub competitor of lowbush blueberry in the northern forest is mountain laurel (*Hall 1963, Shelford 1963*). Invasion of the shrub layer by pioneer tree species rapidly reduces the abundance of lowbush blueberry (*Shelford 1963*).

LIFE HISTORY

Blueberry flowers appear with the leaves in spring. Flower buds are formed during the previous season, and the pinkish-white bell-shaped flowers are arranged in elongated clusters (*Eck 1966, Gleason 1963b, Shutak and Marucci 1966*). Insects, specifically wild and honey bees, are the chief pollinating agents of highbush and lowbush blueberries. Both fruit yield and fruit size are a function of the bee population in a given area (*Martin 1966; Marucci 1966; Shutak and Marucci 1966*). Highbush blueberry fruit matures from 50 to 90 days after bloom, while lowbush blueberries mature from 90 to 120 days after bloom. Lowbush blueberry flowers from April to June. The fruit is available from July to September (*Van Dersal 1938*). Highbush blueberry flowers from May to June, and the fruit is available from June to August (*Kender and Brightwell 1966, Van Dersal 1938*).

Highbush blueberry plants bear fruit when 8 to 10 years old, but some plants may bear fruit as early as the third year (*Taylor 1962*). An established mature bush can be expected to yield 8 to 10 pints of fruit per year; however, fruit production may vary with local conditions (*Taylor 1962*). Fruit yield of lowbush blueberry is usually lower than that of highbush blueberry because of relatively poor blossom set. This reduced ability to set blossoms is attributed to various degrees of self-sterility in large clones (*Aalders and Hall 1961*). Also, velvet-leaf blueberry pollen is incompatible with lowbush pollen. If velvet-leaf blueberry (*V. myrtilloides* Michx.) is present in the stand, lowbush pollen will be diluted and fruit production will be reduced (*Aalders and Hall 1961*).

Blueberries reproduce from seeds, sprouts, underground stems, and suckers. Seed is disseminated chiefly by animals, from June through September. On sites previously uninhabited by blueberry plants, seedlings become established in open areas on exposed mineral soils. Highbush blueberries are usually crown-forming plants 6 to 15 feet high, which may consist of several stems. Individual plants sometimes tend to sucker at the base and form extensive colonies. Lowbush blueberries may form extensive colonies by means of underground stems (*Camp 1945*). Growth of both species is comparatively slow even on the best sites. Highbush blueberry will attain a height of 6 to 15 feet in 8 to 10 years (*Taylor 1962*). I found no growth-rate figures for lowbush blueberry. The maximum height growth for lowbush blueberry is about 2 feet.

Both species are intolerant to shade and are found in open woods or clearings. Encroachment by shade-tolerant species restricts blueberries to openings in the stand or quickly relegates them to suppression and eventual elimination if no openings are provided. After fire or logging, lowbush blueberry will become reestablished from roots within the area (*Hall 1955*).

USE BY WILDLIFE

Blueberries are important to American wildlife (*Martin et al 1951*). For several species of grouse, blueberries are among the most important summer and early fall foods. They also are part of the diet of other upland game birds such as bobwhite, wild turkey, and mourning dove. Many song birds, including the scarlet tanager, bluebird, and thrush, also feed on blueberries. Fur and game mammals such as the black bear, red fox, cottontail rabbit, eastern and spotted skunk, and the fox squirrel utilize the fruit, twigs, and foliage of the blueberry. Part of the diet of the white-footed mouse consists of blueberry fruit. White-tailed deer browse the branches and foliage and eat the fruit (*Martin et al 1951; Van Dersal 1938*). Because of the dense shrubby growth often produced by highbush blueberry, and its high food value, it can be a desirable hedgerow plant, providing both food and cover for a variety of song birds, ruffed grouse, and cottontail rabbit.

PROPAGATION

Seed and stock are available commercially for highbush blueberry, but are not commonly available for lowbush blueberry. Highbush blueberries are commonly propagated by hardwood cuttings obtained from healthy shoots of the past season's growth, ¼-inch diameter or less. Shoots are gathered in the spring just before bud growth starts—15 March to 10 April in New Jersey (*Doehlert 1953*). Fruit buds are undesirable on shoots used for cuttings and should be rubbed off if present (*Mainland 1966*). Shoots should be cut into pieces 3 to 5 inches long, using either a sharp knife or pruning shears. The cut is usually made below the bud for small quantities of twigs, but for large quantities a bench saw is used and bud position is ignored.

The cuttings should be treated with a fungicide and set in either a box frame, solar frame, or open frame containing an equal mixture of sand and horticultural peat (*Doehlert 1935*). About 75 percent of the cuttings should root. Rooting has taken place when the terminal bud begins to green. Liquid fertilizer (either 15-30-4 or 13-26-13, at 1 ounce of concentrate per 2 gallons of water) can be applied to rooted cuttings during the summer, but its use should be discontinued in time to allow adequate tissue hardening—mid-August in New Jersey (*Doehlert 1953*). Young plants can be left in the propagating beds over winter, or they can be transplanted into nursery beds in early fall to allow adequate root growth before winter.

Seeds are commonly used to propagate lowbush blueberry; this method may also be used to propagate highbush blueberry. Berries should be collected when ripe, and chilled at 50°F for several days. Seeds can be removed from the berry by shredding in a food blender for 30 seconds (*Morrow et al 1954*). Sound seeds will settle to the bottom. Stratification may be beneficial in hastening germination. Seeds should be planted in a mixture of sand and horticultural peat. Seedlings will begin to emerge in a month and will continue to emerge for a long period thereafter. Seedlings can be transplanted to other flats after they are 6 to 7 weeks old. Seed may be kept under normal refrigeration and will remain viable for as long as 12 years (*Darrow and Scott 1954*).

Young highbush blueberry plants can be transplanted into the field after the first season. Spacing between plants ranges from 4 to 8 feet between plants and 8 feet between rows. Lowbush blueberries may be established in barren areas by using a golf-hole cutter to remove sod containing roots from a vigorous stand and transplanting it to the desired area (*Hitz 1949, Eggert 1955*). The distance between holes should be no more than 8 inches. Blueberries are exacting in their site requirements and attempts at establishment on less favorable sites have been disappointing (*Kender and Brightwell 1966*). If blueberries are present naturally, in most situations a desirable stand can be cultured.

MANAGEMENT

Lowbush blueberries are often found in the undergrowth of open forest stands in a suppressed stage in which they rarely flower and bear fruit. Removal of competing vegetation will stimulate the blueberry's root system and increase the vigor, abundance, and fruit yields of the plants (*Hall 1955, 1963*). For maximum flowering and fruiting of blueberries, competing vegetation should be reduced to a minimum. This can be accomplished by shallow cultivation or, in the case of lowbush blueberries, light burning in the spring once every 2 or 3 years (*Chandler 1943, Shutak and Marucci 1966*). Care must be taken to avoid fires hot enough to destroy the roots from which new shoots will appear. Pruning is beneficial to both species because fruit is borne abundantly on 1-year shoots rather than on old mature branches.

When enlarging a field from an adjoining woodland, it is advisable to clear the land slowly by cutting and burning a strip 2 or 3 feet wide each year. The overstory must be removed gradually over a period of several years (*Hall 1955*). The herbicides 2,4-D and 2,4,5-T applied on foliage, stems, or stumps will control blueberries.

BRAMBLES

Also called Blackberry, Dewberry, Groundberry, and Raspberry.

ALLEGHENY BLACKBERRY, *Rubus allegheniensis* Porter

BLACKCAP RASPBERRY, *Rubus occidentalis* L.

CANADIAN or THORNLESS BLACKBERRY, *Rubus canadensis* L.

FLOWERING RASPBERRY, *Rubus odoratus* L.

NORTHERN DEWBERRY, *Rubus flagellaris* Willd.

RED RASPBERRY, *Rubus strigosus* Michx.

SWAMP GROUNDBERRY, *Rubus hispidus* L.

By Earl L. Core
West Virginia University
Morgantown

SPECIES

No one knows how many kinds of brambles there are in eastern North America, but more than 500 have been named. Classification of the brambles has been thoroughly treated in other publications (*Bailey 1941-45; Bailey 1947; Bailey 1949; Davis et al 1967-70*).

Blackberries have erect stems, usually angled in cross-section, and armed with large sharp spines. There are usually five leaflets. Dewberries and groundberries have prostrate, trailing stems. Raspberries have erect canes, usually white-powdered, round in cross-section, and often without spines or with weak hairlike spines. There are usually three leaflets. Also, in raspberries the fruit is thimble-like or cap-like, the dry receptacle remaining on the bush; while in blackberries the receptacle itself becomes fleshy and is removed with the fruit.

RANGE

Brambles are found throughout the Northeast. Those listed above are common and widespread, but many other important species occur (*Davis and Davis 1953, Fernald 1950, Strausbaugh and Core 1953*). Red raspberry, Canadian blackberry, swamp groundberry, and northern dewberry are common in the higher elevations and northward, while Allegheny blackberry, blackcap raspberry, and flowering raspberry are more abundant at lower elevations and latitudes (*Shelford 1963*).

HABITAT

Typically the brambles are plants of old fields and woodland clearings. The various species are acclimated to practically all the extremes that occur in the Northeast.

Brambles grow well in a great variety of soils and topographic conditions. Red raspberry is frequent in acid barrens at the higher elevations, where it grows with other acid-loving plants such as blueberries, huckleberries, menziesia, azaleas, mountain laurel, great laurel, and teaberry. Swamp groundberry is widespread in mountainous areas in low boggy places or upland mossy lands. It is associated with cranberries in sphagnum bogs or with teaberry and other plants in mossy uplands.

There are numerous other similar species of groundberries. Northern dewberry is most common northward, but despite its name, ranges south to Georgia, trailing in dry fields and along road banks.

Blackberries generally occupy an intermediate temporary stage in old fields, associated with hawthorns, crabapples, sassafras, fire cherry, black cherry, and other pioneer trees. They are quickly eliminated as overgrowing trees provide too much shade. Allegheny blackberry and many other blackberries are common in dry places from lowlands to uplands, open places in woodlands, along roadsides, in old fields, fence-rows, clearings, and thickets. Canadian blackberry, one of the taller and later-flowering species, is very common in woods, old fields, cool hollows, and along roadsides, mostly in the mountainous regions.

Flowering raspberry is abundant in shady places in woods, along roads and in thickets. Blackcap raspberry is common in woods, borders, fields, fence-rows, and thickets. It is often associated with black walnut trees, a situation unfavorable to many plants. In a study of succession on abandoned farm fields in southern Illinois, blackcap raspberry first appeared 3 years after abandonment and was still present after 40 years. It remained important as long as fields were open and decreased with the increase of woody vegetation. Sassafras, persimmon, and winged sumac were among the first woody invaders (*Bazzaz 1968*).

LIFE HISTORY

Brambles are perennial; in most species the root lives for many years and the stems live for only 2 years. First-year stems are usually sterile and have leaves unlike those of the second year. Flowers and fruit are borne the second year. In most species, flowers appear in May and June, and fruits are ripe in early summer. In the Canadian blackberry, however, ripe fruits persist into September. No figures on seed production per plant were noted. The seeds are spread mostly by birds.

Brambles reproduce from seeds, sprouts, layers, and underground stems. Vegetative propagation is the primary source of development of the dense colonies often seen in old fields. New colonies on freshly exposed areas develop from seeds. Growth of most brambles is more vigorous in full sunlight than in shade. Blackberries grown in shade are often nearly or quite thornless, but produce few fruits. In full sunlight the thornless habit disappears, but fruit production is greatly enhanced. Raspberries, in contrast, seem to do better in partial shade. In the Southeast their habitat preference often puts the brambles in direct competition with Japanese honeysuckle.

USE BY WILDLIFE

Blackberries and raspberries stand at the top of summer foods for wildlife. Even dried berries persisting on the canes are eaten to some extent into fall or early winter; the principal use, however, is while the fruits are juicy. Nearly all species are palatable to human tastes, and probably are equally so to wildlife (*Chapman 1947d*). Another important factor is the widespread availability of brambles in all parts of the Northeast—indeed, in nearly all parts of the United States and Canada.

Birds are especially prominent as users of the fruits. Blackberries and raspberries are important to game birds such as grouse, ring-necked pheasant, and bobwhite quail, and to such common songbirds as catbird, cardinal, yellow-breasted chat, pine grosbeak, robin, orchard oriole, summer tanager, brown thrasher, thrushes, and towhees. Blackberry and raspberry fruits are also important foods of raccoons, chipmunks, and squirrels, as well as other small animals. Deer and rabbits make extensive use of leaves and stems (*Martin et al 1951*).

Because of their habit of forming extensive colonies the various species of brambles have much value as cover for wildlife. The thorny canes create nearly impenetrable thickets where birds, rabbits, and other animals find relative security. In winter, rabbits nibble the stems while at the same time finding security from enemies. Colonies of brambles are common nesting sites for small birds (*Martin et al 1951*).

PROPAGATION

Horticultural varieties of blackberry and raspberry are readily available from nurseries. Dewberry or groundberry stock is also available, although less readily. Since commercial culture is usually for fruit production, nurseries propagate brambles vegetatively from tip layers, root cuttings, and suckers.

Brambles tolerate a wide range of soil types, textures, and pH values; but adequate soil moisture is critical for fruit production. Commercial stands produce best on deep sandy loam with a large supply of humus. Transplanting is done during the dormant season, usually in early spring, and transplanting after growth has started is avoided. Growing stock, propagated in any manner, is generally cut back to ground level when transplanted (*Mecartney 1945, Darrow and Waldo 1948*).

Tip layering is a simple, naturally occurring process recommended for raspberries (*Mecartney 1945*). Raspberry canes grow so that by late August or September the tips reach the ground, and many of these will form new plants naturally. To insure large numbers of new plants, cane tips should be set 4 to 6 inches straight down into the ground, and the soil should be formed around them. Canes are ready for layering when the tips have elongated so that a bare portion extends 3 to 6 inches beyond the last small set of leaves. Rooting will begin in about a week, and rooted tips can be cut from the parent plant and transplanted the next spring (*Darrow and Waldo 1948*).

Blackberries send up suckers, and new plants are usually obtained by digging and transplanting these suckers (*Mecartney 1945, Darrow and Waldo 1948*). Root cuttings provide another simple method of propagating blackberries. Roots ¼ inch or more in diameter are dug in the fall or early spring, and divided into pieces 3 inches long. These are planted horizontally in trenches about 3 inches deep, and by the following fall new plants will have developed (*Darrow and Waldo 1948*).

Brambles can be propagated from seed in the field or nursery. Blackberry seeds have extremely hard coats. Untreated seeds germinated over a period of 3 to 5 years, with very little germination the first year (*Heit 1967b*). To obtain maximum germination the first year, the seeds must be treated so that water can penetrate the coat. Cleaned seed should be soaked in concentrated sulphuric acid for 50 to 60 minutes at 75 to 80°F (*Heit 1967a*). Shorter treatments are less effective and longer ones will cause injury. Seeds should be thoroughly washed immediately after acid soaking, and planted in late August or early September. In nurseries seeds are sown on peat moss or light soil; in the field they should be sown on mineral soil.

Raspberries do not have the extreme hard seedcoat of blackberries. A long warm-and-cold stratification period will usually give good germination, and fresh cleaned seed may be sown in late summer. However, better and more uniform germination can be obtained if raspberry seeds are given a 10- to 30-minute sulphuric acid treatment before sowing in late summer (*Heit 1967, pt. 7*). Treated blackberry and raspberry seeds may be planted in early spring, but they require a 1- to 3-month cold stratification period at 34 to 38°F. This stratification treatment is recommended for seeds of all brambles that are to be spring-planted (*Heit 1967b*).

MANAGEMENT

Besides providing food and cover for wildlife, brambles have great erosion-control value. Many species form dense thickets rapidly, and some form dense mats on the ground. Most species grow satisfactorily in very barren and infertile soils; and they invade and rapidly occupy burns, eroded areas, old fields, and logged areas (*Barrett, Farnsworth, and Rutherford 1962; Van Dersal 1938*). Because there are so many species and they are so abundant, it is seldom necessary to establish brambles. Direct-seeding would be justified if it were important to establish cover quickly or to insure development of the desired species in a new opening.

Openings are the key to managing bramble patches, because invading trees and shrubs quickly eliminate most brambles. Bramble patches can be encouraged or rejuvenated by removing overhead shade, mowing, light burning, or deep cultivation. Mowing and burning stimulate sprouting in addition to removing competing vegetation. Deep cultivation (6 to 9 inches) cuts the roots of existing brambles, and causes the formation of large numbers of sucker plants.

Benzabor (disodium tetraborate pentahydrate 54.50 percent and disodium tetraborate decahydrate 35.5 percent with trichlorobenzoic acid 8 percent), applied with hand-operated mechanical spreaders or blast guns in early spring and summer, is effective against brambles (*Waestemeyer 1963*).

CHECKERBERRY WINTERGREEN

Gaultheria procumbens L.

Also called Checkerberry, Grouse Berry, Mountain Tea, Partridge Berry, Teaberry, Winterberry, Wintergreen, and many other common names (*Krochmal et al 1969*).

By Sadie L. Robinette
West Virginia University
Morgantown

RANGE

Checkerberry wintergreen or teaberry occurs from Newfoundland to Manitoba south to Virginia, Kentucky, and Minnesota, and in the mountains to Georgia (*Gleason 1963c*).

HABITAT

Checkerberry wintergreen is hardy throughout the Northeast. It requires acid soil and usually grows within the pH range of 4.0 to 6.0 (*Wherry 1920 and 1957*) In a mature beech-maple forest in Ohio, checkerberry wintergreen was found growing where the pH of the soil ranged from 3.5 to 6.9 on the surface to 4.0 to 6.9 below the surface. Its distribution was independent of pH value within these ranges (*Stone 1944*). However, a pH of 4.5 to 6.0 has been reported as optimum for the growth of checkerberry wintergreen, with 7.0 the maximum pH it will tolerate (*Spurway 1941*)

As long as the soil is acidic, checkerberry wintergreen will grow well on many soil types, including peat, sand, sandy loam, and coal spoil banks. It will tolerate site conditions ranging from dry to poorly drained (*Wilde 1933*).

Checkerberry wintergreen is commonly found in heath shrub communities that are characteristic beneath many forest types, including both pine and hardwoods in New England, and jack pine and spruce-larch forests in the Lake States (*Braun 1950, Hosley 1938, Kittredge 1934*). It also occurs in bogs and as an invader of old fields in many parts of the region (*Strausbaugh and Core 1958:708*). Mountain-laurel, rhododendron, azaleas, blueberries, huckleberries, and trailing arbutus are the most common heath associates of checkerberry wintergreen.

In Maine, checkerberry wintergreen is abundant in grouse coverts in both upland and lowland hardwoods and mixed hardwood-conifer stands. The tree associates are yellow birch, sugar maple, beech, white birch, aspen, and spruce; and the ground cover associates include bunchberry, clover, partridgeberry, celandine, and shinleaf (*Brown 1946*). In Massachusetts, checkerberry wintergreen colonized abandoned farmland along with common juniper, flowering raspberry, and sumacs (*Hosley and Ziebarth 1935*). It also volunteered on coal spoil banks in central Pennsylvania, where it formed part of the shrub layer beneath aspen-fire cherry stands. The common shrubs growing with it were sweetfern, Allegheny blackberry, smooth and staghorn sumac, and prairie willow (*Bramble and Ashley 1955*).

LIFE HISTORY

Checkerberry wintergreen's small, white, perfect flowers are borne from June to September. The bright red fruit ripens in the fall, and often remains on the plant until early the next summer (*U. S. Forest Service 1948:187*). The fruit is rather dry and consists of fleshy flower parts surrounding a dry capsule, which contains many minute seeds (*U. S. Forest Service 1948*). There are approximately 2,800 fresh fruits per pound, and about 3,000 dried fruits per pound (*Swingle 1939, U. S. Forest Service 1948, Van Dersal 1938*). Individual plants usually bear 2 to 6 berries.

I found no information concerning the longevity of this perennial plant, or the age at which it first produces fruit. The growth rate is slow, and there is little hazard of spreading from planted specimens (*Ruffner 1965*).

Checkerberry wintergreen reproduces vegetatively from root suckers (*Hosley 1938*). Seeds are probably the source of new plants colonizing old fields, and birds may disseminate the seeds.

Checkerberry wintergreen is shade-tolerant, but most fruiting occurs in openings (*Edminster 1947:120*). Heavy fruiting often follows cutting of timber (*Hosley 1938*).

USE BY WILDLIFE

Checkerberry wintergreen is not taken in large quantities by any species of wildlife, but the regularity of use enhances its importance (*Edminster 1947, Martin et al 1951*). It is a year-round fruit producer, and one of the few sources of green leaves in winter (*Brown 1946, McAtee 1914*).

White-tailed deer and ruffed grouse are the most important users of checkerberry wintergreen. Grouse eat both fruit and leaves throughout the year, and in some localities teaberry is one of the most important grouse foods (*Brown 1946, Edminister 1947, Hosley 1938*). White-tailed deer browse teaberry throughout the region, and in some localities it is an important winter food (*Hosley and Ziebarth 1933, Watts 1964*).

Other animals that eat checkerberry wintergreen are wild turkey, sharp-tailed grouse, bobwhite quail, ring-necked pheasant, black bear, white-footed mouse, and red fox (*Hosley 1938, Martin et al. 1951, Van Dersal 1938*). Teaberries are a favorite food of the eastern chipmunk, and the leaves are a minor winter food of the gray squirrel in Virginia (*Dudderar 1967, Van Dersal 1938*).

PROPAGATION

Checkerberry wintergreen has been cultivated at various times in the past, but seed and growing stock are not usually available from nurseries (*Rehder 1940:739*). Commercial seed consists of the dried fruits, which number about 3,000 per pound. Seed may be collected locally at any time in the fall after ripening (usually early September). Seed is extracted by drying the fruit until it is brittle and powdery and then rubbing it through a 30-mesh screen (*U. S. Forest Service 1948*). The number of clean seeds per pound has been reported as 163,000 and 2,870,000 to 4,840,000 (*Swingle 1938, U. S. Forest Service 1948*).

The seed has a dormant embryo, so it must be either planted in the fall or stratified before spring planting. Probably the easiest way to propagate small quantities of teaberry is by sowing whole fruits soon after collection in the fall. Fruits should be sown outdoors in moist, acid soil in a shady location. Seedbeds should be protected from rodents over winter.

For spring planting, seed should be cleaned soon after collection, and then stratified for 30 to 75 days at 41°F before planting. Because of its minute size, clean seed should be scattered on or pressed into peat, and then protected with a pane of glass placed about 4 inches above the soil. Seedbeds should be shaded. The soil should be moist, porous, and acidic; mixtures of sand and peat are usually used (*U. S. Forest Service 1948*).

Checkerberry wintergreen can be propagated at any time during the spring and summer by simple layering. It reproduces vegetatively from root suckers, and new plants may be obtained during the spring or fall by digging and transplanting suckers. Clumps of checkerberry wintergreen can also be divided and transplanted during the spring or fall (*Bailey 1950, Laurie and Chadwick 1931*).

Establishment in the field should be limited to acid sites, and plants will do best in partial shade.

MANAGEMENT

Checkerberry wintergreen is ordinarily plentiful in the woodlands of the Northeast, and no special care is needed to keep it growing (*Hosley 1938*). Fruit production can be stimulated by thinning timber stands and removing overtopping vegetation.

Checkerberry wintergreen is recommended to the suburban gardener as an ornamental and for attracting songbirds (*Mason 1945, McAtee 1914 and 1936*). It can be planted under taller shrubs and in other partially shaded acid sites. Attractive groups of ground cover plants can be formed from checkerberry wintergreen, partridgeberry (*Mitchella repens*), bearberry (*Arctostaphylos uva-ursi*), bunchberry (*Cornus canadensis*), and Canada beadruby (*Maianthemum canadense*) (*Mason 1945*). Song birds will eat the fruits year-round, particularly during winter when few other fruits are available.

Checkerberry wintergreen was controlled by droplet spraying of the foliage with D-T, an equal mixture of 2,4-D and 2,4,5-T. A D-T mixture was more effective than 2,4-D alone. A 0.25-percent concentration of D-T killed checkerberry early in the growing season, but a 0.5-percent solution was more effective later in the summer (*Egler 1949*).

CHERRIES

COMMON CHOKECHERRY, *Prunus virginiana* L. Also called Black Chokecherry or Chokeberry, Cabinet Cherry, California Chokecherry, Caupulin, Cerisier, Chokecherry, Eastern Chokecherry, Rum Chokecherry, Western Chokecherry, Whiskey Chokecherry, and Wild Black Cherry.

By James R. Vilkitis
University of Massachusetts
Amherst

RANGE

Chokecherry grows from the Arctic Circle to Mexico and is one of the most widely distributed shrubs or small trees of North America. It occurs from Newfoundland and eastern Quebec across the continent to British Columbia, south to California, Arizona, New Mexico, Kansas, Missouri, Illinois, Indiana, Maryland, and Maine, and also southward in the Appalachians to parts of Kentucky, Virginia, North Carolina, and Georgia (*Little 1953*). In the mountains, in West Virginia at least, chokecherry has a scattered distribution (*Strausbaugh and Core 1952-64*).

HABITAT

Chokecherry is a hardy plant that, once established, defies northern extremes of climate. It occupies adverse sites such as moving sand dunes (*Schlatzer 1964*) and frost pockets where temperatures drop to 40°F below zero (*Harlow 1957*).

Occurring commonly in almost all soils of the Northeast, chokecherry can be found in a wide variety of habitats, from rocky hills and sand dunes to borders of swamps. It is even found on the spurs of Mt. Katahdin, Maine, at an elevation of 4,000 feet (*Mathews 1915*). Chokecherry sometimes occurs in open woodlands, but it is more often associated with old fields, fence rows, roadsides, river banks, forest margins, and waste-corner thickets of farms. The species grows best in rich, well-drained, moist soil with ample sunlight, but it is also found in the shade on poor, dry soils (*Van Dersal 1938*). Optimum soil pH was reported as 6.0 to 8.0 (*Spurway 1941*).

Throughout its entire range, chokecherry is found in nearly all wooded areas (*Harlow 1957, Rogers 1906*). In the moving, slightly acid sand dunes it is a pioneer species associated with *P. besseyi*, *P. serotina*, *Pyrus baccata*, *Spiraea billiardii*, and *Lonicera ledebourii* (*Schlatzer 1964*). In dune depressions and sand flats it grows with *Carex pensylvanica* var. *digyna*, *Symphoricarpos occidentalis*, *Rosa woodsii*, and *Agropyron* spp. (*Hulett et al. 1966*). In the Northern Great Plains, chokecherry grows in shelter belts in combination with *Ulmus pumila*, *Fraxinus pennsylvanica*, *Acer negundo*, and *Prunus americana* (*George 1936*). On moist sites it is found with *Crataegus douglasii*, *Amelanchier florida*, *Rosa* spp., and *Symphoricarpos* spp. (*Shelford 1963*).

LIFE HISTORY

The white, densely elongated clusters of strongly-scented flowers bloom from April to July. In northern areas the flowers open later. The thick-skinned, edible fruit is about 5/16 inch in diameter. It ripens from July to September but remains astringent until ripe. Typically, the lustrous clusters of red or amber fruit turn dark red to purplish black at maturity. However, some varieties of chokecherry have different fruit colors. For example, in *P. virginiana* var. *leucocarpa,* the fruit is canary yellow when mature. Fruiting is abundant in most years, but production per plant is unknown. No information was found regarding seed-bearing age of trees.

Birds and mammals are the chief means of seed dispersal. Pits are dropped by birds throughout the fruit-bearing season and later. Primary reproduction of chokecherry is through seed. Once established it grows rapidly and often forms dense thickets of suckers and sprouts from an extensive lateral root system. (*Brown 1922, Otis 1960, Van Dersal 1938, Vines 1960*).

In most of its range chokecherry is a tall shrub. Only under the most favorable climatic and soil conditions does it become a small tree, 20 to 30 feet high, and it rarely exceeds 8 inches dbh.

Chokecherry is a very competitive shrub, due to its tolerance of adverse climatic and site conditions such as cold temperatures, shade and drought, and its ability to sprout prolifically. The adaptability of chokecherry is indicated by its exceptionally wide geographic distribution. However, chokecherry is subject to many disease and insect attacks, notably black knot disease (*Hepting 1971, Hosley 1938*) and defoliation by tent caterpillars.

Chokecherry is a host of the apricot ring pox virus, twisted leaf in sweet cherry (*Lott and Keane 1960*), and the notorious X-disease virus that infects peach and cherry trees (*Gilmer et al. 1954, Wolfe 1955*). Infected trees can be symptomless. X-disease spreads rapidly and can ruin an orchard in 3 or 4 years. This disease has caused considerable damage to peach orchards in New York since 1938 (*Palmiter and Hildebrand 1943*). It has been reported in the Maritime Provinces (*Callahan 1964*), Wisconsin, Michigan, Pennsylvania, and Connecticut. In areas where chokecherry is rare, as along Lake Ontario, X-disease is unknown (*Parker and Palmiter 1951*).

USES

Good crops of fruit are born in most years (*Vines 1960*), and about 70 species of game or song birds seek out fruits as soon as they become available (*Bump et al 1947, Longenecker and Ellarson 1960, Van Dersal 1938*). Chokecherries are readily eaten by ruffed grouse through the fall till December, but may be less important locally than pin or black cherries (*Edminster 1947*). The fruits are also eaten by small mammals (*Grimm 1951*), and the buds and twigs are browsed by ruffed grouse during winter (*Phillips 1967*). Rabbits have little taste for the bitter twigs of chokecherry (*Harlow 1957*), but repellents may not keep them from eating the bark (*Detroux and Fouarge 1952, Vines 1960*). Chokecherry stems ranked fairly high in winter feeding of cottontails in Connecticut (*Dalke and Sime 1941*).

In northern forests during winter, white-tailed deer and snowshoe hares eat chokecherry, but utilization differs with locality. In southern forests use of cherry species is low (*Taylor 1961*). Moose on winter range in Wyoming showed a high preference for chokecherry (*Harry 1957*), and black-tailed deer in Utah used it as a summer staple (*Smith 1952*).

Chokecherry has fair cover value for small mammals and nesting birds, particularly where it forms thickets (*Longenecker and Ellarson 1960*) but is of questionable value for landscaping, because of insect and disease susceptibility. Erosion control and shelterbelts are other important uses. And in some instances the fruit is eaten by humans; it makes a jelly with an almond-like flavor (*Hosley 1938*).

PROPAGATION

Because of the genetic variability of chokecherry and its wide geographic range, seed should be collected or purchased near the area of planting to insure local adaptability and prevent introduction of strains that may be undesirable.

Seed can be gathered in August to September, either from the ground or by flailing fruit from the trees onto ground cloths. Cleaned seed is sometimes available commercially, and samples have proved 97 percent pure and 94 percent sound (*U. S. Forest Service 1948*). Reported numbers of cleaned seed per pound averaged 5,800, ranging from 3,000 to 8,400 (*Engstrom and Stoeckeler 1941, U. S. Forest Service 1948, Van Dersal 1938, Vines 1960*). Yields of clean seed per 100 pounds of fruit averaged 16 pounds, ranging from 7 to 24 pounds (*Swingle 1939*).

Optimum seed storage conditions are unknown, but good results were obtained from sealed dry storage at 26°F (*U. S. Forest Service 1948*), and seeds of pin cherry have kept for as long as 10 years when stored in sealed containers at 34 to 38°F. Temperatures warmer than about 40°F would probably reduce viability.

Sowing in either September or spring has been recommended. If seeds are to be sown shortly after collection, depulping is not essential, but seed cleaning and a water soak before planting may be beneficial (*Heit 1968*). Cleaned seed to be used in spring planting should be stratified in moist sand or peat for 120 to 160 days at 41°F (*Krefting and Roe 1949*) or for 60 to 90 days at 50°F (*Barton 1939*) before sowing. Seed may germinate in stratification if held too long. Stratified seed should be sown in the spring in drills at 25 seeds per linear foot, covered with ½ inch of mulch until germination begins, and protected from birds and rodents (*U. S. Forest Service 1948*). The germination rates in one study were between 30 and 70 percent, with a 4:1 ratio between viable seed sown and usable seedlings produced (*Engstrom and Stoeckeler 1941*).

In the nursery, chokecherry is sometimes attacked by the fungus *Coccomyces lutescens* and the bacteria *Bacterium prunii*. Spraying with 4-6-50 or 3-4-50 bordeaux mixture or a 2-percent solution of lime sulfur will control the fungus (*U. S. Forest Service 1948*).

Field planting of various species of cherries is usually done with 1-0 stock on deep well-drained soil in sunny locations free of frost pockets (*U. S. Forest Service 1948*). Specific suggestions on field planting of chokecherry were not found, but this species grows better in partial shade than most other cherries.

MANAGEMENT

Chokecherry is a useful species for wildlife food and cover, erosion control, shelterbelts, and ornamentals. However, the usefulness of the species is impaired by its disease-hosting qualities and livestock-poisoning risk. The leaves are poisonous when wilted (*Harlow 1957*), and chokecherry should not be planted or maintained in pasturage (*Van Dersal 1938*). Its use as an ornamental may also be limited where risk of tent caterpillar infestation is high, but has been recommended for dry, shady locations (*Curtis and Wyman 1933, Kammerer 1934*).

PIN CHERRY

PIN CHERRY, *Prunus pensylvanica* L.f. Also called Bird Cherry, Cerises d'Ete, Fire Cherry, Northern Pin Cherry, Petit Merisier, Pigeon Cherry, and Wild Red Cherry.

By John R. Fulton

Northeastern Forest Experiment Station
Morgantown, West Virginia

RANGE

Pin cherry occurs from Newfoundland and southern Labrador to northern Ontario and west across Canada to British Columbia and south to the Rocky Mountains in Minnesota, Iowa, northern Illinois, northern Indiana, Pennsylvania, and New York and in mountains southward to Virginia, North Carolina, northern Georgia, and eastern Tennessee (*Little 1953*).

HABITAT

Pin cherry is a northern species; south of Pennsylvania it occurs only in the mountains. Throughout its range, the number of days of snow cover varies from 1 to 10 in the south to 120 days or more in the north, and the average growing seasons are 100 to 210 days (*Van Dersal 1938*). Average annual precipitation varies from 30 inches in Canada to 80 inches in the Great Smokey Mountains (*U. S. Department of Agriculture 1941*).

Pin cherry grows on many kinds of soil, from infertile sand to rich loam (*Hosley 1938, Keeler 1915*). Optimum soil pH is about 5.0 to 6.0 (*Spurway 1941*). In the north, pin cherry is found in nearly all forest types, usually in clearings, where it often forms thickets. In the south it grows at elevations of about 2,500 to 4,500 feet (*Core 1929, Stupka 1964*). Pin cherry attains its largest size on western slopes of the Great Smokey Mountains in eastern Tennessee (*Sargent 1949*).

A shade-intolerant pioneer species, pin cherry often invades roadsides, old fields, burns, and similar openings. It often dominates these sites either in pure stands or with species such as aspen, red maple, black cherry, and white or gray birch (*Society of American Foresters 1967*). It is characteristic as a short-lived tree in hemlock, northern hardwoods, and spruce-fir forests (*Core 1929, Shanks 1954*). Pin cherry is a dominant natural revegetation species of coal-spoil banks in Pennsylvania (*Bramble and Ashley 1955*).

LIFE HISTORY

Pin cherry flowers from April to early June, when the leaves are half grown. The flower is perfect, white, ½ inch across, and is born on a slender stalk in a four- or five-flowered group which usually is clustered with two or three other groups. The fruit is a red drupe, ¼ inch in diameter, and is thin-skinned and sour. Fruits ripen from July to August and may persist on the trees until October or later

(*Keeler 1915, U. S. Forest Service 1948*). Seed dispersal by birds and gravity occurs from July into the winter months (*Keeler 1915, U. S. Forest Service 1948*).

In a 4-year study in West Virginia involving pin cherries with an average dbh of 4.7 inches, the average fruit yield was 0.68 quarts per tree, half the trees bore fruit, and fruit yields varied substantially among years. The average fruit-ripening date was 31 August, and the latest date of fruit persistence was 6 October (*Park 1942*).

Pin cherry usually occurs as a tree 31 to 40 feet tall at maturity, but in the southern Appalachians specimens up to 91 feet tall and 5 feet 4 inches in circumference have been found (*Stupka 1964*). Pin cherry aggressively invades cleared areas and grows fast, particularly when young (*Keeler 1915*). Once established, it will reproduce by suckering and sometimes forms thickets on poor soils (*Wright 1915*). However, it is susceptible to several fungous diseases and parasitic insects, and has a shallow root system. Pin cherry seldom lives over 30 years and is usually replaced by shade-tolerant trees (*Hosley 1938*).

USE BY WILDLIFE

Pin cherry is an important wildlife food source. The fruit is eaten in summer and fall by at least 25 species of non-game birds, several upland game birds, fur and game mammals, and small mammals (*Martin et al 1951*). Pin cherry fruit constituted 4.5 percent of the fall diet of ruffed grouse in the Northeast (*Edminster 1947*). The buds are used by upland game birds, especially sharptailed and ruffed grouse. Foliage and twigs are browsed by deer (*Martin et al 1951*); however, a study showed the foliage to have an undesirably high calcium to phosphorus ratio for good deer nutrition (*Bailey 1967*). Pin cherry is also browsed by the cottontail rabbit (*Sweetman 1944*).

Pin cherry provides only fair nesting cover and materials for birds (*Longenecker and Ellarson 1960*), but this value would presumably be greater where pin cherries form dense thickets.

Beaver will cut pin cherry, sometimes completely removing small stands at the detriment of other wildlife.

PROPAGATION

The ripened fruits can be collected in late summer from trees or the ground. They should then be cleaned of pulp and can be sown early in the same fall, by planting 1 inch deep in mulched beds. Soaking the seeds in water before planting may be of benefit, but scarification is not necessary (*Heit 1967c*). If seeds are to be held over winter, they should be stratified in moist sand for 60 days at 68 to 86°F, then for 90 days at 41°F (*U. S. Forest Service 1948*). Seeds of pin cherry have retained viability for as long as 10 years when stored in sealed containers at 34 to 38°F (*Heit 1967e*).

The yield of cleaned seed was reported as 16 pounds per 100 pounds of fruit, and the number of cleaned seed per pound averaged 15,700 (*U. S. Forest Service 1948*). Seed may be available commercially from at least one source, but planting stock apparently is not sold (*NE Regional Technical Center 1971*).

Pin cherry is used as grafting stock because the wood unites readily with that of sour cherry (*P. cerasus*) (*Wright 1915*). Stocks are worked more commonly by budding than by grafting (*Bailey 1950*).

Little is known about field propagation of pin cherry, but recommendations for nursery practices may suggest field techniques. Once established, pin cherry usually maintains itself until it is overtaken by competing trees. It suckers readily and should grow well from root cuttings (*Bailey 1950*).

MANAGEMENT

Pin Cherry is a convenient species for use by wildlife managers who desire a fast-growing, aggressive, small tree that is widely utilized by game and other animals. It will provide quick cover on denuded land because it tolerates extreme soil conditions. Seeds of pin cherry have very hard coats and accumulate in the humus layer of the forest floor. They will germinate profusely when influenced by fire or lumbering operations (*Hosley 1938*).

Pin cherry will produce well under moderate to heavy deer browsing, and should be browsed at least moderately to keep plant growth within reach of deer (*Aldous 1952*).

But, most commonly, the wildlife values of pin cherry are obtained incidentally to its occurrence rather than through purposeful management. Despite its desirable qualities of wildlife use, soil-binding capability, and stock for commercial cherries, pin cherry is not widely cultivated.

Pin cherry is plagued by several diseases and parasites, which may spoil its appearance, at least. The most prominent leaf disease is cherry leaf spot, caused by the fungus *Coccomyces hiemalis*. This disease results in characteristic holes in the leaves and premature leaf fall. Repeated attacks reduce vigor of the tree. Another common disease is black knot, caused by the fungus *Dibotryon morbosum*. This can be recognized by the numerous large black galls on the branches and twigs (*Hepting 1971*). The eastern tent caterpillar (*Malocasoma disstria*) sometimes completely defoliates cherries. Although pin cherries withstand repeated attacks of these insects, dead limbs, defects, and growth loss may occur (*Kulman 1965*).

Pin cherry has been controlled by spraying mixtures of 2,4-D and kerosene on foliage, stems, or stumps (*Day 1948*). Equal mixtures of 2,4-D and 2,4,5-T also have proved effective in killing seedlings and suckers (*Egler 1949*).

SWEET CRAB APPLE

Malus coronaria (L.) Mill.
(*Pyrus coronaria* L.)

Also called American Crabapple, Crabapple, Fragrant Crab, Garland-Tree, Narrow-Leaf Crab-Apple, Scented Crab, Wild Crab, Wild Crab Apple, and Wild Sweet Crab Apple.

By Robert W. Donohoe
Ohio Department of Natural Resources
New Marshfield

RANGE

Sweet crab apple does not occur naturally in the New England States or the Maritime Provinces. Range of the typical form is from central New York and southern Ontario to southern Wisconsin, south to Delaware, and in uplands to South Carolina, Tennessee, and Missouri. The variety *dasycalyx* is common in the western part of this area, particularly in Ohio and Indiana, and ranges to Minnesota and Kansas. Along the southern Appalachians, sweet crab apple occurs up to altitudes of 3,300 feet (*Fernald 1950, Little 1953, Sargent 1922*).

HABITAT

The range limits of sweet crab apple indicate that it is not adapted to the colder climates, northward or at high elevations, within the Northeast. Within its range limits, crab apple occupies a wide variety of soils and topographical situations (*Charles M. Nixon, personal communication concerning Ohio; Van Dersal 1938*). The tree does best in full sunlight on moist but well-drained, fairly heavy soils (*Hough 1907, Van Dersal 1938*). The soil pH preferences are not documented, but may approximate those for prairie crab apple (*M. ioensis*): 6.0 to 6.5 for nursery soils and 5.5 to 8.0 for field soils (*Wilde 1946*). Although sweet crab apple does best on moist, rich soils, it will tolerate drier soils of moderate fertility (*Edminster 1947, Van Dersal 1938*).

Sweet crab apple is often found in forest glades among taller trees (*Hough 1907*). In Ohio it is associated with old-field succession and commonly occurs with hawthorn, elm, ash, hickory, and sumac (*Charles M. Nixon, personal communication*). In southeastern Ohio, sweet crab apple on slopes of northern exposure is associated with pawpaw, flowering dogwood, hawthorn, American hophornbeam, sourwood, pin cherry, and sassafras; on ridges with serviceberry, pawpaw, flowering dogwood, common apple, and sassafras; and on flood plains with pawpaw, spicebush, wahoo, wild plum, and elderberry (*Hart 1951*).

A survey of spoil resulting from strip-mining for limestone in northeastern Ohio (Stark County) revealed good natural plant invasion and establishment after 21 years. Sweet crab apple had become established along with white ash, black cherry, American elm, red elm, cottonwood, sassafras, hawthorn, and red-osier dogwood (*Riley 1952*).

LIFE HISTORY

The flowers of sweet crab apple appear in March to May and are white and flushed pink. The fruits ripen in late summer or early fall, are yellow-green in color, and are 1 to 1¼ inches in diameter (*U. S. Forest Service 1948, Van Dersal 1938*). Leaf color in the fall is yellow, and nearly all leaves are off by November 1.

In Michigan an 8-year study of fruit production by 13 species of plants that may be used by wildlife showed that crab apple had the largest mean weight (103 g, range 1.2 to 162.9 g) per square foot of crown surface (*Gysel and Lemmien 1964*). In another Michigan study, sweet crab apple was considered to be a heavy and consistent fruit producer. The fruits ripened by October; nearly all had fallen by December 1, but some persisted until January 1. Fruits softened after falling and were badly discolored by December 1 (*Hosley 1938*). A fruit-production survey on sweet crab apple in southern Ohio (Scioto County) for three successive years revealed that out of a sample of 100+ trees, 40 percent produced fruit in 1935, 10 percent produced fruit in 1936, and 50 percent produced fruit in 1937 (*Chapman 1938*).

The fruit of sweet crab apple contains 4 to 10 small- to medium-size dark seeds. Heavy seed crops are produced every 2 to 4 years, and medium to light crops in intervening years. One pound of cleaned seed can be obtained from 100 pounds of fruit (*Swingle 1939*). The average number of cleaned seed per pound was reported as 14,000, but may be as much as 70,000 (*Edminster 1947, Isely 1965*). In nature, the seed is disseminated by gravity and animals (*U. S. Forest Service 1948*).

Sweet crab apple reproduces primarily from seed. The tree attains the height of 25 to 30 feet, has a trunk rarely more than 12 to 14 inches in diameter, and when isolated develops a broad top, 20 to 25 feet in diameter, with rigid branches bearing many short branchlets terminating in sharp spur-like leafless tips (*Hough 1907*).

The sweet crab apple is not shade-tolerant. It is part of the old-field succession and often forms dense spiny thickets when it does not have competition from overstory trees. It is sometimes found growing in the forest understory; however, in this situation, growth is poor and fruit production is minimal.

USE BY WILDLIFE

The apples include about 25 species, many of which are of value to wildlife, and one of the chief uses of sweet crab apple is for wildlife food (*U. S. Forest Service 1948*).

Data about use of sweet crab apple are scanty. But the following information about all apple species collectively seems to apply reasonably well to sweet crab apple. Ruffed grouse, ring-necked pheasant, and bobwhite quail eat the fruit, seeds, and buds of apple. The purple finch, grackle, blue jay, baltimore oriole, orchard oriole, robin, yellow-bellied sapsucker, starling, tufted titmouse, rufous-sided towhee, cedar waxwing, and the downy, hairy, red-bellied, and red-headed woodpeckers eat the fruits and seeds. The fruit and bark of the apple are eaten by the black bear, gray and red fox, opossum, porcupine, cottontail rabbit, raccoon, eastern skunk, fox squirrel, deer and pine mouse, and Allegheny wood rat. The twigs and foliage are browsed by white-tailed deer (*Martin et al 1951*).

A food-habit study of white-tailed deer in Ohio showed that fruit of the sweet crab apple ranked first in the diet of animals from the eastern part of the state (*Nixon and McClain 1966*).

Sweet crab apple provides excellent cover for many wildlife species, especially where it forms dense spiny thickets in old fields.

PROPAGATION

Ripe crab apples can be picked from the trees or gathered from the ground in September or later. A bushel of fruit yields 2 to 3 pounds of cleaned seed; and, as a rule of thumb, a pound of cleaned seed may produce about 2,000 usable seedlings (*Edminster 1947*).

Seeds can be extracted by macerating the fruit in water and floating off or screening the pulp. The wet seed mass can be fermented, in a waterbath with yeast added, but must not remain in the bath longer than 48 hours (*Edminster 1947*). Cleaned seed should then be dried, and, if necessary, can be stored in sealed containers, at temperatures just above freezing. Apple seeds (*M. pumila*) stored in this way retained viability for at least 2½ years (*U. S. Forest Service 1948*).

Seeds can be stratified in moist sand or peat at 41°F for 60 to 120 days. The longest period, 120 days, hastened subsequent germination (within 24 days), whereas the germination time was longer (within 104 days) following 60-day stratification. In other words, total time to germination was about 21 weeks with 120-day stratification and over 23 weeks with 60-day stratification (*U. S. Forest Service 1948*).

Fresh seeds can be sown in the fall, at the rate of 1 pound of seed per 100 square feet of soil, and then covered with ¼ inch of soil plus mulch (*Edminster 1948*). Seeds of a closely related species (*M. ioensis*), collected when slightly green and sown immediately, germinated 100 percent the following spring. Alternatively, stratified seed can be sown in the spring, preferably in drills (*U. S. Forest Service 1948*).

Optimum planting density in the nursery is about 10 plants per square foot. Seedlings are ready for outplanting when about 6 inches tall by 3/16 inch diameter above the root collar, as 1-0 or 2-0 stock (*Edminster 1947*).

Sweet crab apples can be outplanted in a variety of soils and site conditions. They do best when grown in a moderate temperate climate on a clay-loam soil (*U. S. Forest Service 1948*). Fallow fields, fields in the early successional stages, and forest openings are places where sweet crab apple can be established.

Flowering crab apple (*Malus* sp.), at least, can also be propagated by whip grafting onto apple seedling roots in January or February. The stocks are dug in the fall and stored until used. Six- or 8-inch scions should be used on about 3-inch root pieces. The unions are tied with waxed string, and the grafts are stored overwinter like hardwood cuttings, or set singly in boxes of moist peat and lined out in a similar way in the spring. If set deep in the soil, many of them develop their own roots (*Laurie and Chadwick 1931*).

MANAGEMENT

Sweet crab apple in old fields can be managed by preventing the invasion of overstory species. Cutting, girdling, or using herbicides on invading trees, which would eventually cause shade, may be the best management technique.

Sweet crab apple may be controlled in part by using herbicides equivalent to 2,4-D, or 2,4-D and 2,4,5-T (equal parts of each). When used at the rate of 3,000 parts per million, diluted in water and applied to foliage, these herbicides gave good control on young seedlings, but only fair control on older trees (*Rudolf and Watt 1956*).

MISCELLANY

The wood of sweet crab apple is heavy, close-grained, not strong, light red, with yellow sapwood of 18 to 20 layers of annual growth. It is used for levers, tool handles, and many small domestic articles. The tree is sometimes planted in gardens in northern and eastern states (*Sargent 1922*).

The fruit of sweet crab apple makes a delicious marmalade or jelly (*Fernald and Kinsey 1943*), or cider and vinegar (*Isely 1965*).

Crab apples are susceptible to air-pollution damage from HCl, Cl_2 and ozone (*Sucoff and Bailey 1971*).

— — — —

DOGWOODS

FLOWERING DOGWOOD, *Cornus florida* L. Also called Arrowwood, Boxwood, Cornelius-Tree, Dogwood, False Box, Florida Dogwood, Nature's Mistake, White Cornel.

ALTERNATE-LEAF DOGWOOD, *Cornus alternifolia* L.F. Also called Blue Dogwood, Gray Dogwood, Green Osier, Osier, Pagoda Dogwood, Red Osier.

ROUNDLEAF DOGWOOD, *Cornus rugosa* Lam. Also called Bois de Calumet.

SILKY DOGWOOD, *Cornus amomum* Mill. Also called Kinnikinnik, Red Willow, Silky Cornel, Squawbush.

By Walter A. Lesser
Department of Natural Resources
Elkins, West Virginia

and

Jean D. Wistendahl
Ohio University
Athens

RANGE

The four species of dogwood discussed here are found in most of the Northeast, but two are rare or absent in Canada.

Flowering dogwood ranges north from Florida and Texas to southwestern Maine and southern New Hampshire and Vermont, west to southern Ontario and Michigan and south to Missouri and Kansas (*Little 1953*).

Alternate-leaf dogwood ranges farther north, into New Brunswick and Nova Scotia and westward along the St. Lawrence valley to the northern shores of Lake Superior and to eastern Minnesota. The southern limits are eastern Kentucky, Ohio, West Virginia, Maryland, Delaware, and New Jersey (*Sargent 1922*).

Silky dogwood ranges from southern Maine to southern Illinois and Indiana south to South Carolina and Alabama (*Gleason and Cronquist 1963*). Roundleaf dogwood, a more northern species, is found from Quebec to northern Ontario, south to New Jersey, Pennsylvania, northern Ohio to northeastern Iowa, and in the mountains to Virginia (*Gleason and Cronquist 1963*).

HABITAT

These dogwoods are found either as understory species in many forest types or as thicket-forming shrubs of fields and wet areas. Within the ranges of these four dogwoods, annual precipitation varies from a low of 30 inches per year in the north to a high of 80 inches in Florida, where there is no snowfall, to more than 50 inches of snow in the north. Temperature extremes are from −30° to 115°F (*Fowells 1965*). The growing season ranges from 160 days in southern Michigan to 300 or more days in Florida (*Fowells 1965*).

Dogwoods tolerate a wide variety of climatic conditions, but roundleaf dogwood does not range beyond the southern reaches of the Northeast except in the mountains to Virginia (*Gleason and Cronquist 1963*).

Flowering dogwood is one of the most adaptable and widely distributed understory trees of the eastern deciduous forests—growing in a variety of soils from well-drained uplands to the deep, moist soils of streambanks (*Fowells 1965*). It is commonly found on soils having pH values of 5 to 7 (*Spurway 1941*); and optimum growth occurs in moist fertile loam that is slightly acid (*Fowells 1965*). In cutover loblolly pine stands on the Virginia coastal plain, flowering dogwood was most common on soils having good drainage and light texture; it was almost absent on poorly-drained, heavy soils (*Wenger 1956*).

Alternate-leaf dogwood grows in rich woodlands, along the margins of forests and along streams in moist well-drained soils (*Ammons 1950, Sargent 1922*) as well as in dry woods and on rocky slopes (*Fernald 1950*). Silky dogwoods occurs in more moist situations, especially along streams (*Ammons 1950, Gleason and Cronquist 1963*) and in swamps and thickets (*Fernald 1950*). Roundleaf dogwood occurs mostly in dry woodlands and on rocky slopes (*Fernald 1950*).

Although flowering dogwood is most prominent in two forest types, scarlet oak and white oak-red oak-hickory, it is found in many hard wood and conifer types (*Fowells 1965*). In the scarlet oak type, dogwood associates are: scarlet, southern red, chestnut, white, and post oaks; hickories; blackgum; sweet gum; black locust; and pitch, shortleaf, and Virginia pines. In the white oak-red oak-hickory type, flowering dogwood is associated with yellow-poplar; pignut, shagbark, and mockernut hickories; white ash; red maple; beech; and blackgum (*Fowells 1965*).

The following species are associated with flowering dogwood in the moist, climax forest understory: magnolias (*Magnolia tripetala, M. macrophylla,* and *M. fraseri*), sourwood, striped maple, redbud, American hornbeam, eastern hophornbeam, American holly, and downy serviceberry (*Braun 1950*). In the hill section of Indiana, flowering dogwood is conspicuous in the understory. It is a dominant understory species in the white oak forests of the Shenandoah Valley (*Braun 1950*).

Alternate-leaf dogwood is among the shrubs that are generally abundant in moist woods, along with spicebush, witch-hazel, pawpaw, and wild hydrangea (*Hydrangea arborescens*) (*Braun 1950*). In oak forests at moderate elevations, the understory may include alternate-leaf dogwood, witch-hazel, mountain-camellia (*Stewartia ovata*), mountain winterberry, and Virginia creeper. Rhododendron and mountain-laurel may be present, particularly if eastern hemlock is in the canopy (*Braun 1950*). In the sugar maple-white elm areas in Alger County, Michigan, alternate-leaf dogwood, prickly gooseberry (*Ribes cynosbati*), and virgin's-bower (*Clematis virginiana*) are widely distributed along with more northern species such as American yew, mountain maple, red-berried elder, beaked hazel, and American fly honeysuckle (*Braun 1950*). In Colebrook, Connecticut, alternate-leaf dogwood along with witch-hazel, mapleleaf viburnum, and American fly honeysuckle are frequently found in mature forests (*Braun 1950*).

In the sugar maple-basswood forests of the Midwest, roundleaf dogwood and bush-honeysuckle (*Diervilla lonicera*) are the northern species of shrubs indicative of the transitional nature of this zone (*Braun 1950*). In the mixed forest of the hemlock-white pine-northern hardwoods region, there are a large number of shrubs and small trees including roundleaf dogwood, alternate-leaf dogwood, mountain maple, serviceberry, eastern hophornbeam, American mountain-ash, gooseberries (*Ribes* spp), beaked hazel, rope-bark (*Dirca palustris*), bush-honeysuckle, American fly honeysuckle, and thimbleberry (*Rubus parviflorus*) (*Braun 1950*).

In a study of old fields on the floodplain of the Raritan River in New Jersey, silky dogwood was found in association with blackberries, poison ivy, shining sumac, smooth sumac, blackhaw viburnum, southern arrow-wood, Carolina rose, bayberry (*Myrica pensylvanica*), gray dogwood, and grape (*Wistendahl 1958*).

LIFE HISTORY

The flowers of flowering dogwood are greenish white to creamy, perfect, in heads surrounded by four showy, petal-like, white, deciduous bracts (pink in the form *rubra*) (*Preston 1966*). The flowers open at the same time the leaves expand—in March at the southern end of the range to June in northern areas (*U. S. Forest Service 1948*). The light cream-colored flowers of alternate-leaf dogwood are in broad flat open clusters that open from May in the south to June in the north (*Ammons 1950*). Flowers of the two other species are white, in flat clusters, and appear from May to July (*Ammons 1950*).

Fruiting time varies with species and location. Flowering dogwood has ovoid scarlet fruits ½ inch long and ¼ inch wide with thin, mealy flesh (*Fowells 1965*). The fruits ripen from September to late October (*U. S. Forest Service 1948*). Alternate-leaf dogwood has a dark blue, globe-shaped fruit about ⅓ inch in diameter when it ripens in September (*Ammons 1950*). The fruit clusters are loose, spreading, and red-stemmed (*Brush 1957*). The pale blue fruits of silky dogwood are also in loose clusters and ripen in September (*Ammons 1950*). Fruits of roundleaf dogwood are light blue and sphere-shaped; they ripen from August to October (*Ammons 1950, Fernald 1950*).

Flowering dogwood bears good seed crops about every other year, but seeds from isolated trees are frequently hollow (*U. S. Forest Service 1948*). Both wild and nursery-grown flowering dogwoods fruited for the first time at 6 years of age (*Spinner and Ostrom 1945*). Seed is dispersed in October to late November or later, by gravity, birds, and other animals (*U. S. Forest Service 1948*). The number of seeds per ounce averaged 280, with a range from 200 to 390 (*U. S. Department of Agriculture 1961a*). The yield of seed per 100 pounds of fruit ranged from 22 to 46 pounds, and the average number of cleaned seed per pound was 4,500 (*U. S. Forest Service 1948*).

In a yield and fruit-persistence study of flowering dogwood in West Virginia for a 4-year period, 71 percent of the plants produced fruit, average date of ripening was September 20, and the latest date of fruit persistence on the plants was December 2. The plants exhibited a crop failure in 1 of the 4 years (*Park 1942*). In Texas, 88 percent or more of trees 3½ inches dbh and larger fruited each year. Year-to-year differences were more pronounced in the smaller diameter classes. The fruit ripened in September and some persisted on trees until January. Average fruit production was 37.9 pounds per square foot of basal area (*Lay 1961*). Flowering dogwood yields fruit under a heavy overhead canopy even in a poor seed year if the site is fair to good (*Crawford 1967*).

Alternate-leaf dogwood yields of cleaned seed ranged from 5,900 to 9,500 and averaged 8,000 seeds per pound (*U. S. Forest Service 1948, Vines 1960*). Seed is dispersed from July through September (*U. S. Forest Service 1948*).

Silky dogwood seeds are dispersed from September to mid-October. Seed yields were 17 pounds of cleaned seed per 100 pounds of fruit and 10,900 to 11,600 cleaned seeds per pound (*U. S. Forest Service 1948*). In southwest Michigan, fruits remained on the shrubs for about 90 days after ripening (*Gysel and Lemmien 1955*). The average germination of silky dogwood was reported to be 10 percent (*Forbes 1955*). Annual fruit production for an 8-year period on the Kellogg Forest in Michigan ranged from 0.7 g per square foot of crown surface to 46.6 g and averaged 17.9 g (*Gysel and Lemmien 1964*).

No information was found on seed production of roundleaf dogwood. This species occurs only infrequently throughout its range (*Ammons 1950*).

Natural germination of dogwood seed occurs in the spring after the seed has fallen and lain on the ground over winter. All species of dogwood show delayed germination due to embryo dormancy and, in some species, to impermeability or hardness of the seed coat (*U. S. Forest Service 1948*). The best natural seedbeds are moist, well-drained, rich loams (*Vimmerstedt 1957*).

Flowering dogwood seedlings usually show rapid root growth. Height growth is relatively fast during the first 20 to 30 years but then practically ceases, although individual plants may live 125 years (*Fowells 1965*). Flowering dogwood has a long growing season. In a Massachusetts nursery, flowering dogwood displayed a height growth pattern different from that of any other species studied. The dogwoods grew from 24 April to 4 September, and 90 percent of growth occurred during 95 days from 15 May to 18 August. The most rapid growth occurred during the first week in August, then growth suddenly slowed down.

This species has been reported to grow nearly all summer, but to stop temporarily during periods of adverse conditions (*Kozlowski and Ward 1957*). In the Georgia Piedmont, the most rapid radial growth of stems occurred during an 80- to 89-day period. Half of the total radial growth was completed in 40 to 49 days (*Jackson 1952*).

Soil moisture was the most important factor determining survival of 1-year-old flowering dogwood seedlings in the North Carolina Piedmont (*Ferrell 1953*). In another North Carolina Piedmont study, flowering dogwood seeds were planted in three situations: in an open field, under pine stands, and on the margins of pine stands. Survival was significantly higher on the margins of pine stands than on the other two sites, but there was no significant difference in survival between the open field and the pine forest. The intermediate light intensity of the margins provided some advantage that compensated for a reduced water supply. However, dogwood growth was greater in the open than in the margin or the pine forest. Seedlings in the forest were the smallest (*Kramer et al 1952*).

Flowering dogwood reproduces by sprouting, and it sprouts most profusely when cut in late winter (*Buell 1940*). It also reproduces extensively by layering (*Spector 1956, U. S. Forest Service 1948, Vines 1960*).

Maximum height for flowering dogwood on good sites is about 40 feet, with a dbh of 12 to 18 inches, attained in 20 to 30 years (*Fowells 1965*). Near the northern limits of its range, flowering dogwood becomes a many-branched shrub (*Vimmerstedt 1957*). Alternate-leaf dogwood, under favorable conditions, becomes a small tree not more than 30 feet in height, with a short trunk 6 to 8 inches in diameter (*Sargent 1922*). Silky dogwood, with its upright to spreading form, grows to a height of 3 to 10 feet (*Vines 1960*). Roundleaf dogwood is a shrub reaching 6 to 10 feet (*Ammons 1950*).

Flowering dogwood is well adapted as an understory tree. It has the ability to carry on maximum photosynthesis at one-third of full sunlight, which helps explain how it survives and grows under a forest canopy (*Fowells 1965*). Flowering dogwood is comparable in shade tolerance to white oak (*Vimmerstedt 1957*).

Because flowering dogwood has thin bark, it is readily injured by fire. In the Northeast, fires killed the above-ground parts of all the flowering dogwoods on a study area after 1 year (*Stickel 1935*). Fire-damaged trees, however, have ability to sprout profusely (*Vimmerstedt 1957*). Once trees reach 10 to 15 feet in height they can withstand infrequent winter burns of low intensity (*Halls and Oefinger 1969*).

Flooding is also detrimental to flowering dogwood. In one experiment, flooding killed all potted seedlings in 1 to 3 weeks (*Parker 1950*). Flowering dogwood is also susceptible to drought, although it can tolerate low and high temperatures. In prolonged periods of drought, the leaves often turn red and curl, and severe dieback of the top may result (*Vimmerstedt 1957*).

USE BY WILDLIFE

The dogwoods are extremely valuable for wildlife. The seed, fruit, buds, flowers, twigs, bark, and leaves are utilized as food by various animals.

As a wildlife food, the most distinguishing quality of flowering dogwood is its high calcium content. Samples collected in southern pine-hardwood forests contained 1.72 percent calcium in leaves, 1.44 percent in twigs, and 0.89 percent in fruits. These amounts are well above those needed by wildlife for good skeletal growth (*Halls and Oefinger 1969*). Compared with other fruits, flowering dogwood is outstanding for its content of calcium and fat. Fruit collected in Texas had the following percentage composition: protein 5.49, fat 16.17, fiber 24.64, ash 4.96, phosphorus 0.6, and calcium 1.10. Leaves and twigs contained 1.75 to 2.90 percent calcium (*Lay 1961*).

Alternate-leaf dogwood was deficient in

phosphorus, as were 11 of the 20 plant species analyzed in a study of the mineral content of deer browse on the Huntington Wildlife Forest in New York (*Bailey 1967*).

Flowering dogwood has been recorded as food taken by at least 36 species of birds, including ruffed grouse, bob-white quail, and wild turkey. Records of mammals eating this dogwood include eastern chipmunk, white-footed mouse, gray fox, skunk, cottontail rabbit, white-tailed deer, beaver, and gray squirrel (*Chapman 1947a, Van Dersal 1938, Vines 1960*). In the Missouri Ozarks, flowering dogwood contributed as much or more than any other soft-fruited species to the diet of wild turkeys, and was prominent in the diet of turkeys from fruit ripening in September until February (*Dalke et al 1942*). Dogwood fruit was in 10 percent of 115 crops from wild turkeys collected on the George Washington National Forest during three falls and early winters. Dogwood was fourth in importance among all foods (*Martin et al 1939*). Flowering dogwood ranked 21st on a list of quail food plants of the Southeast, and was listed as a preferred food of the wild turkey (*Vines 1960*). In east Texas, fruit of flowering dogwood was found in 16 percent of 49 deer stomachs collected in November and December. Fruit remains were also found in deer pellet groups (*Lay 1965a*). In a study of cottontail rabbits in southwest Michigan, flowering dogwood rated second among 18 winter food plants (*Haugen 1942*). In Massachusetts, winter food choices among 100 species of woody plants were analyzed for relative attractiveness as food of the cottontail rabbit. Browsing by rabbits severely injured the flowering dogwood but injured alternate-leaf dogwood only slightly (*Sweetman 1944*).

Fruits of alternate-leaf dogwood have been reported eaten by at least 11 species of birds, including ruffed grouse. Black bears may be especially fond of this fruit (*Chapman 1947a*). Leaves and stems are eaten by white-tailed deer and cottontail rabbits (*Van Dersal 1938, Vines 1960*).

Silky dogwood fruit is utilized by at least 10 species of birds (including ruffed grouse, bob-white quail, wild turkey, and ring-necked pheasant), and cottontail rabbit, woodchuck, raccoon, and squirrels. Cottontails eat the fruit and browse the stems (*Holweg 1964, Van Dersal 1938*). In West Virginia, wood ducks readily eat silky dogwood fruits in late summer and fall, before and after ripening. Wood ducks have been seen reaching as far as they can from the water to strip the shrubs of fruit.

Roundleaf dogwood fruit has been found in stomachs of ruffed grouse and sharp-tailed grouse, and feeding observations have been made of the blue-headed vireo, cottontail, and moose (*Van Dersal 1938*). A ruffed grouse from Delaware County, New York, had eaten 226 roundleaf dogwood fruits on December 20 (*Bump et al 1947*).

All species of dogwoods possess cover value, but that of roundleaf is least due to its infrequent occurrence (*Korschgen 1960, McAtee 1936*). Animals trapped or observed in plantings of silky dogwood on the Kellogg Forest in Michigan included short-tailed shrew, striped ground squirrel, red squirrel, white-footed mouse, meadow vole, and meadow jumping mouse (*Gysel and Lemmien 1955*). A study of power line right-of-way vegetation and animal use in southern Michigan revealed that the silky dogwood-willow shrub community was used by cottontails, raccoon, red squirrels, and opossums (*Gysel 1962*). In West Virginia, silky dogwood on streambanks provides brood and escape cover for wood ducks. The thicket-forming silky dogwood also provides cover for woodcock.

PROPAGATION

Because these dogwoods, except roundleaf, are highly prized for ornamental purposes, seed (dried fruit or cleaned stones) and planting stock are available from commercial growers. Dogwoods can be grown from root cuttings, layering, and by division, as well as from seed (*Fowells 1965*). If seed is to be collected, isolated plants should be avoided because they often have a high percentage of empty stones, in flowering dogwood at least (*U. S. Forest Service 1948*).

Because the fruit pulp contains an unknown chemical that delays germination (*Goodwin 1948*), cleaned seeds are preferable for germination in the nursery. The pulp may be removed by soaking fruit in water for a few days until the covering is soft and easy to remove (*Free 1957*). Large quantities of fruit may be macerated in water or run through a hammer mill, allowing pulp and empty stones to wash away (*U. S. Forest Service 1948*). Dogwood seed should then be dried and stored in an air-tight container at 34 to 38° F.

Stratification is necessary to break seed dormancy. The seed can be stratified in moist sand or peat moss for four months at 33 to 41°F. Seed can be sown in drills or broadcast and covered with ¼ to ½ inch of nursery soil depending on the size of the seed. Forty of the smaller seeds are sown per square foot and mulched with leaves or straw. The mulch is removed as soon as germination begins (*U. S. Forest Service 1948*).

In nurseries where small lots of seeds are used, broadcast sowing is recommended; and for fall sowings, heavy mulch is needed for winter protection. A heavy mulch prevents solid freezing of seeds during an open winter and may induce much higher germination the following spring (*Heit 1968*). For seeding in the fall, seeds should be gathered just as they go into the meaty stage, but before the outside coat becomes hardened or impervious to moisture and air.

In one test, seeds of alternate-leaf dogwood gathered and planted on 8 July attained a germination of 100 percent the following spring. Roundleaf dogwood seed gathered and planted on 2 September also had a germination of 100 percent the following spring (*Titus 1940*). But seeds of alternate-leaf and roundleaf dogwoods usually are extremely dormant and probably should be sown in July or early August or stored, stratified, and seeded in the spring as previously described. Silky and flowering dogwood seed are less dormant and may be fall-seeded in September or October (*Heit 1968*). One author reported greater success with spring seeding than fall seeding and used builder's sand as the stratification medium (*Miller 1959*). Nursery germination of flowering dogwood seed may range from about 77 percent to 85 percent (*U. S. Forest Service 1948*).

The number of usable plants (1-0 or 2-0 stock) per pound of clean seed was 200 for flowering dogwood and 1,400 for silky dogwood (*Bump et al 1947*).

Dogwoods are reproduced vegetatively by various means: softwood cuttings in summer, hardwood cuttings in winter, grafting in winter or spring, layering in spring and summer, from suckers and divisions in spring, and budding in the summer (*Mahlstede and Haber 1957*). Vegetative reproduction is necessary to propagate plants for characteristics such as color of flowers and fruit retention.

Flowering dogwood roots readily from cuttings taken in June or immediately after the plants bloom. The advantages of taking cuttings early in the season are that they obtain maximum growth and harden off before the first winter. Only terminal shoot tips should be used, trimmed to 3 inches in length and leaving two to four leaves (*Pease 1953*). One author claimed that rooting was faster when four leaves were retained rather than two (*Doran 1957*). Dogwood cutting results were better when a medium of sand or sandy soil was used rather than peat moss (*Doran 1957, Pease 1953, Vermeulen 1959*). The cutting bases should be dipped in a mixture of indolebutyric acid crystals and talc, one part acid crystals to 250 parts talc by weight. Cuttings are then set 1-1/4 inches deep in the rooting medium. The cuttings should be removed in early August and placed in a cold frame in light, well-drained soil with a pH of about 5.0 (*Pease 1953*). Cuttings from young trees usually show better growth after rooting than do cuttings from mature trees; also the survival of rooted cuttings from old trees may be poor (*Doran 1957, Pease 1953*). In addition to the indolebutyric acid treatment, one author reported that wounding the cuttings provided a better distributed root system (*Bridgers 1955*).

The red form of flowering dogwood (*C. f. rubra*) is difficult to start from cuttings and is usually propagated by budding in late summer or whip-grafting in winter on flowering dogwood seedlings (*Hartmann and Kester 1968*).

Dogwoods can be propagated successfully by grafting during the winter or early spring months. Scions may be collected in advance of the grafting work, and stored for 3 or 4 weeks in plastic containers with a small amount of sphagnum moss to prevent drying. Scions should be restricted to wood of the previous growing season. Wood to be used as scions should be about the diameter of a lead pencil, 8 to 12 inches long, and should contain three or 4 sets of buds (*Coggeshall 1960*). Grafting techniques most commonly used include the whip-and-tongue method, side graft, and bench or bare-root graft (*Coggeshall 1960, Wells 1955*). A disadvantage in the whip-and-tongue method is the total loss of the seedling rootstock in the event of graft failure. This does not occur when a side graft is used (*Coggeshall 1960*).

Some dogwood graft failures have been attributed to a black mold fungus appearing as a crumbly, crust-like black layer on cut surfaces of both the rootstock and scion. The mold prevents callus formation. Growers have reported losses as high as 60 to 70 percent of their grafts. Control of this fungus is through sanitation and use of healthy vigorous stock (*Collins 1960*).

Dogwoods are budded in late July or early August, using 1-year-old seedlings in the field. The shield or T-bud method is normally used, placing the bud as low as possible and on the southwest side of the seedling. This results in a straight plant. The following spring, before the bud starts growth, the tops of the seedlings are removed by cutting just above the new bud union (*Shadow 1959*).

Layering is a satisfactory method of propagating dogwoods. Plants produced by layering soft, growing shoots are often superior to those raised from hardwood cuttings. Layering is done by starting against the base of the stock plant and working out, layering the shortest shoots first. A slight twist is all that is needed, but small pegs should be used to keep the layers firm. The layers are lifted the following spring and lined out 1 foot apart (*Sheat 1953*).

Division of dogwoods is carried out just before spring growth. Plants are lifted, pulled apart with small divisions, and lined out about 10 inches apart (*Sheat 1953*).

Transplanting flowering dogwoods with a root ball is preferred over bare-root transplanting, although both methods can be successful. Plants entering their third year are well suited for planting in permanent locations. Plants of this age are usually 2 to 3 feet tall and can be dug easily without excessive disturbance to the root system, thereby insuring unchecked growth after transplanting. The transplants may be fertilized with a mixture of cottonseed meal and superphosphate in early spring at the rate of 5 to 7 trowels-full per plant (*Miller 1959*). Alternate-leaf dogwoods are easily transplanted with bare roots when the shrubs are less than 3 feet in height (*Brush 1957*). Dogwoods should be transplanted only in the spring (*De Vos 1953, Wister 1950*).

MANAGEMENT

Although flowering dogwood fulfills requirements of many wildlife species for food and cover, it is seldom planted for this purpose, but may be a practical means of improving wildlife habitat where fruit-producing hardwoods are scarce (*Halls and Oefinger 1969*). Flowering dogwood has been suggested for planting along streams, at the edge of farm woodlots, and around farm ponds (*Chapman 1947a*). It certainly commands attention in the management of understory plants for forest game habitat.

Silky dogwood was highly regarded by game managers for use in ruffed grouse management in southern Michigan (*Zorb 1966*). This shrub has been especially useful for streambank stabilization when planted in combination with grasses (*Porter and Silberberger 1960*). Silky dogwood has also been used successfully in strip-mine reclamation (*Bramble 1952, Hart and Byrnes 1960*).

Field plantings of flowering dogwood in the Northeast have not been especially successful. Survival in 22 plantings after 5 to 12 years ranged from poor to excellent, being satisfactory in only 13 plantings. Most plantings had grown only about 3 feet in 5 to 8 years. None had reached site domination or a complete canopy. Retarding factors seemed mainly to be poor soil and herbaceous plant competition (*Edminster and May 1951*).

In a study of flowering dogwood survival in the North Carolina Piedmont, improvement of forest soil moisture conditions was considered the most important initial step in securing satisfactory reproduction. Soil moisture conditions may be improved by the use of a heavy harrow or disk plow to break up the surface organic matter and cut out some of the competing roots. This should be a good method for use in a good seed year, but an immediate cutting of the overstory is not desired. The result from exposing mineral soil should be a satisfactory stand of dogwood reproduction even under a fairly dense canopy. Releasing this reproduction at a later date would be important (*Ferrell 1953*).

Flowering dogwood may be reproduced from stump sprouts by cutting trees in late winter. Tallest dogwood sprouts have been produced by cutting in March. For discouraging dogwood sprouting, midsummer cutting is recommended (*Buell 1940*).

Of 59 silky dogwood plantings in the Northeast, 37 had excellent and 19 had good survival. The few failures were attributed to excessive grass competition or infertile soil. Survival was about the same from Vermont to West Virginia. After 12 or 13 years, plantings had reached heights of 8 to 12 feet on better soils but only 5 to 6 feet on some poorly drained, acid soils in New York (*Edminster and May 1951*). When 20-year-old plantings were checked in New York State, silky dogwood was found to have grown vigorously and dominated all the sites (*Smith 1962*). Survival of silky dogwood on strip-mine spoilbank plantings has ranged from 45 to 72 percent, and it is a promising species for spoilbank reclamation (*Bramble 1952, Bramble and Ashley 1949, Hart and Byrnes 1960*).

When silky dogwood is to be planted, 1- or 2-year-old nursery-grown seedlings are recommended. The top growth of nursery stock should be pruned back to a height of 3 to 6 inches just before planting. Like most hardwood shrubs, competition from other plants retards early growth. Hence, plantings should be made in plowed furrows or scalped sod areas. For complete site dominance, silky dogwood seedlings should be spaced 3 to 4 feet apart (*Edminster and May 1951*).

Use of inorganic nitrogen fertilizer has stimulated radial growth of dogwoods of various ages on soils of low to moderately low fertility. Nitrogen was applied as ammonium nitrate, 32 1/2 percent, at various rates. Marked growth response occurred the first growing season after fertilization. The response was less favorable the second year and insignificant the third year. A nitrogen application of 500 pounds per acre resulted in almost maximum growth response (*Curlin 1962*).

The quality of flowering dogwood browse has been improved by controlled burning, especially burning in the spring rather than in fall or winter. Summer burning probably would be as good as spring burning. Burning increased the protein and phosphoric acid content of browse (*Lay 1957*).

Diseases and parasites that attack the dogwoods include noninfectious diseases resulting from an unfavorable environment, parasitic diseases, nematodes, and insects. Noninfectious diseases include sun scald, mechanical and drought injury, freezing, and improper soil nutrient balance (*Beecher et al 1964*). Diseases and insects may kill dogwoods, but in most cases are only detrimental to the health and vigor of the trees.

The common diseases of flowering dogwood include spot anthracnose caused by the fungus *Elsinoe corni* and *Septoria* leaf spot. The spot anthracnose fungus attacks leaves, bracts, stems, and ripe fruits and affects mostly the lower crown. The symptoms are spots about 1 mm in diameter on the blooms and leaves. Centers of the small spots fall out, giving a shot-hole appearance to the leaves. The appearance of the blooms may be seriously affected. If the disease is not controlled, it may become so severe that flower buds never open (*Beecher et al 1964, Cleveland 1951*). This infection can be controlled by spraying four times per year with either captan 50 percent wettable powder, 1 1/2 tablespoons per gallon of water; 3/4 tablespoons of maneb 80 percent wettable powder per gallon of water; or folpet 75 percent wettable powder at the rate of 2 tablespoons per gallon of water. The first application is made in early spring when the flower buds are beginning to open. The second spray is applied as soon as the bracts have fallen, the third spray 4 weeks later, and the fourth in late summer after the new flower buds are well formed (*Beecher et al 1964*).

Septoria leaf spot appears on flowering dogwood about mid-June in Virginia. It is caused by the fungus *Septoria cornicola*, which overwinters on leaves, either on the ground or on leaves remaining attached to the tree. The symptoms are numerous small angular spots bordered by veins. The spots are purple at first, then become paler in the center, but rarely drop out. The spots may also blacken and roughen the fruit. Control consists of spraying with water solutions of captan, maneb, or zineb. Adding 1/4 teaspoon of a liquid household detergent to each gallon of spray helps insure complete foliage wetting. The first application should be made in early spring when the buds begin to open. A second application is necessary in June and a final spraying in August (*Beecher et al 1964, Hepting 1971*).

Additional information about these and other foliage diseases of flowering dogwood is given in a recent handbook by Hepting (*1971*).

Trunk canker, a steam disease most frequently found on low-vigor flowering dogwoods, is caused by the fungus *Phytophthora cactorum*. This disease is also called crown canker or collar rot. Twigs and large branches die as the disease progresses. Infected trunk tissues are discolored, and a black fluid often exudes from the canker. The canker slowly enlarges, extending completely around the base of the tree; and a collar of rot develops, eventually followed by the death of the tree. No satisfactory control for this disease is known. Small cankers, if detected in time, may be cut out and the wound dressed, but large cankers usually cannot be removed successfully. This is a disease of ornamental flowering dogwood that often follows injuries such as those caused by lawn mowers or boring insects (*Beecher et al 1964, Hepting 1971*).

The most common stem disease of forest-grown flowering dogwood is the target canker caused by *Nectria galligena*. Only occasional trees are infected (*Hepting 1971*).

The most damaging insect enemies of the dogwoods are the dogwood borers. They feed in the bark and cambium but not the sapwood. The larvae frequently kill young trees, and reduce the vitality and kill branches on older trees. Trees infested with borers have swollen areas on the trunk near the ground or at the main crotches. Since larvae enter only through a definite break in the outer bark, all injuries to the trunk and branches of a dogwood should be avoided to prevent infestation. Pruning wounds or injuries should be treated with wound dressing. Some borers enter terminal twigs. Dead twigs should be pruned back to healthy wood and the wound dressed. The pruned twigs should be burned to destroy the borers. The trunks of newly transplanted trees may be wrapped with crepe paper to protect these trees from borer attack through unnoticed injuries. Insecticides may be used to control the overwintering borers (*Beecher et al 1964, Schread 1957, Westcott 1951*).

Dogwood club gall is caused by infestation with midge larvae (*Mycodiplosis alternata* Felt) and has become serious in some areas. The orange-colored maggots overwinter in the soil under dogwood trees. Pink flowering dogwoods seem to be infested most often; serious infestation will stunt the trees and kill most of the flower and leaf buds that develop beyond the galls. Excellent control of the gall may be obtained by spraying with carbaryl at the rate of 2 pints per 100 gallons of water. The spray material should be applied at weekly intervals from late May until the end of June. Trees sprayed six times were free of galls (*Schread 1964*).

Dogwoods are usually desirable, but certain situations may warrant control of these plants. In the South, complete control has been obtained by the application of picloram at the rate of 0.7 pounds per 100 gallons of spray. Leaf-stem application produced the best results. The degree of coverage by the spray material on thickets of dogwood was not critical (*Nation and Lichy 1964*). Picloram plus 2,4,5-T ester, 1½ pounds of each per acre, was also effective; 74 percent of flowering dogwoods were top-killed at the end of the second growing season after treatment (*Brady 1969*). But 2,4,5-T alone resulted in a lower kill of flowering dogwood, 22 percent, when helicopter-sprayed at the rate of 2 pounds acid equivalent per acre on logged and uncut areas in West Virginia (*Wendel 1966*).

In the South, flowering dogwood was successfully controlled by injection of 2,4-D amine concentrate (*Moyer 1967*) and was reported as susceptible to either 2,4-D amine or fenuron pellets (*Cech and Mulder 1964*). However, in recent observations in West Virginia, flowering dogwood was highly resistant to treatment with fenuron (25 percent) pellets broadcast at rates of 20, 40, and 60 pounds per acre. Each treatment readily killed the overstory oaks, whereas the dogwoods responded to being released by growing and fruiting vigorously during the 4 years of observation after the treatments. This observation, and another in Pennsylvania (*Shipman and Schmitt 1971*), shows that fenuron can be used successfully to release flowering dogwood and other shrubs overtopped by low-value hardwood trees.

Flowering dogwood is beneficial in limiting movement of nutrients (particularly calcium) through the soil profile, thus keeping them available in the rooting zone of other species (*Thomas 1967*). Having a very high content of calcium in the foliage, flowering dogwood often creates its own high soil pH. Dogwood litter decomposes very rapidly, thereby making it a prime soil builder when compared with low-calcium species such as oaks or pines (*Hepting 1971*).

GRAY DOGWOOD

GRAY DOGWOOD, *Cornus racemosa* Lam. Also called Gray-Stemmed and Panicled Dogwood.

By Stephen A. Liscinsky
Pennsylvania Game Commission
State College

RANGE

This species occurs in all but the northern and easternmost parts of the region. It grows from central Maine to southern Ontario and southward to Maryland, West Virginia, Kentucky, Missouri, and Oklahoma.

HABITAT

The wide range of gray dogwood indicates the many climatic conditions it will tolerate. Its ability to grow on a variety of sites is equalled by few other shrubs. In central Pennsylvania alone it is found from moist lowlands to dry uplands in medium- to heavy-textured soils (*Heyl 1954*). The top 4 inches of soil in these Pennsylvania sites had the following ranges in characteristics: pH 4.6 to 7.8; percentage organic matter 1.3 to 5.0; phosphorous 0.0 to 7.5 ppm; and potassium 15 to 338 ppm (*Heyl 1954*).

Gray dogwood is most commonly found growing in thickets along fencerows and woods edges and in abandoned fields. Although found mostly in pure thickets, it will persist for a considerable time in mixtures with other species. Hawthorns, elms, and ashes are common overstory associates, while grasses, sedges, goldenrod, and cinquefoil are common ground cover companions (*Liscinsky 1960*).

LIFE HISTORY

In June or July the shrub is often covered with small pyramidal clusters of little creamy-white blossoms, which are followed in September and October by showy clusters of white berry-like and brightly red-stalked fruits. If not eaten by wildlife, the fruit persists long after the leaves have fallen. Gray dogwood is well known for producing good to heavy crops of seed annually. Dissemination of the seed is largely credited to wildlife, especially birds.

Gray dogwood thickets seem to originate at a central point from seedlings that in turn spread by means of root suckers.

Gray dogwood is a slow-growing shrub. At 10 years of age a stand of gray dogwood is seldom more than 6 feet in height, with maximum stem diameters of 1 inch. At about 20 years it reaches its maximum height of 9 feet and stem diameters up to 1½ inches. Maturity is reached at this time, and the stand either gives way to more tolerant, longer-lived species, or regenerates itself if there is no competition. Stand density decreases from 120 to 20 stems per 100 square feet from ages about 5 to 15 years (*Liscinsky 1960*).

Tolerance to shade is considered intermediate. Removal of some overstory competition has been found beneficial to gray dogwood.

USE BY WILDLIFE

The fruits of gray dogwood are readily eaten by wildlife, especially by birds. Gray dogwood is an important cover plant for woodcock and ruffed grouse. Woodcock use thickets of gray dogwood from spring to fall for nesting, feeding, and resting. Grouse may be flushed from these thickets at any time of the year, but there is no record of nesting in them. For food and cover for wildlife, and its many other desirable attributes, gray dogwood is a highly desirable plant for wildlife. Deer browse the plant, but it is low on the preference scale.

PROPAGATION

Seed and stock are usually available commercially, but less available than other dogwoods such as flowering and silky dogwoods. Seeds average about 12,000 per pound, and average germination in tests was 31 percent, though a potential of 50 to 75 percent can be expected (*U. S. Forest Service 1948*). Dogwood seeds are dormant and require several months of warm, moist treatment before cold stratification for satisfactory germination (*Heit 1968*). The ideal way to handle the species is to collect mature fruit, clean the seeds, and plant them in early August (*Heit 1968*). In one case, seeds collected green in July and sown immediately gave full germination the next spring. Cleaned seeds may also be stratified and held for planting in April or early May. For long-term storage, seeds should be cleaned, air-dried at low humidity, placed in sealed containers and kept at 34 to 38°F (*Heit 1967e*). Seed stored this way will retain excellent germination and vigor for 4 to 8 years (*Heit 1967e*).

The seeds are usually sown in drills, sometimes broadcast, and are covered with ¼ to ½ inch of soil. Forty seeds per square foot are recommended (*U. S. Forest Service 1948*).

I had some success in planting 1-year-old seedling stock, but recommend 2-year-old stock. Success was definitely better on the more fertile soils and where the sod was removed before planting (*Liscinsky 1960*).

Generally speaking, success in planting this dogwood has not been as good as with others. However, most dogwoods can be grown from seeds, from root cuttings, by layering, and by division (*U. S. Forest Service 1948*).

MANAGEMENT

Management of this species is not difficult. Emphasis should be placed on caring for stands that become established naturally. This involves provision for some direct sunlight and elimination of some competing trees. Growing in thickets, adjacent to hawthorn and alder patches, this species is especially beneficial to wildlife. Establishment by planting should be reserved for areas where no gray dogwood exists and where the soil is suitable.

RED-OSIER DOGWOOD

RED-OSIER DOGWOOD, *Cornus stolonifera* Michx. Also called Hartes Rouges, Kinnikinnick, Red-Stemmed Cornel, and Squawbush.

By Margaret Smithberg
University of Minnesota
St. Paul

RANGE

Red-osier is most common in glaciated areas of the northeastern and midwestern states and provinces. South of the glaciated areas, it occurs locally near Washington, D. C., and in West Virginia, Ohio, Illinois, Indiana, Iowa, and Nebraska.

HABITAT

Although optimum conditions for the species have not been described, red-osier dogwood is somewhat restricted by high temperatures. Its southernmost limit is Washington, D. C., while in Canada it extends up to the tundra lines.

The species is characteristic of swamps, low meadows, and river and creek banks. However, it is also found commonly in drier situations such as fields and woods borders and may be cultivated in drier soils (*Grimm 1952*).

It is highly adaptable to soil type, being found for example on rich-woodland soil, silt loam, fine sandy loam, poorly drained muck, gravelly sand, boulder till clay, sandy upland soil, calcareous gravel, dolomite sandstone, heavy clay with peat, bottomland silt, and dry humus peat.

Red-osier dogwood, as a dominant member of "edge" vegetations, is also adaptable to soil reaction. It is tolerant of alkaline soils (*Van Dersal 1938*) and was found in a wide range of pH values: 8.0 near lake outlets, 6.0 for sedge and northern white-cedar swamps, and 3.2 for sphagnum mats (*Jewel and Brown 1929*).

Since red-osier dogwoods growing in the poorer soils are likely to grow slowly and produce less fruit, the characteristics of soils that yield vigorous growth are more useful in choosing high-quality planting sites or suitable nursery soils. A Wisconsin sampling of vigorous stands led to these soil fertility standards for red-osier dogwood: pH 5.0-6.0, base exchange capacity 6.0 M.E./100 g., total nitrogen .07 percent; and these amounts of nutrients in pounds per acre: N–15, P_2O_5–75, K_2O–150, and replaceable calcium-1,200 (*Wilde 1946*).

The species plays a major role in many plant communities. It is commonly present along stream banks and shores with alder, birch, and willow, and is a dominant in wet lowlands with sedges, poplars, and black spruce. It is one of the earliest shrubby plants to become dominant in bogs and swamps, due to its ability to live with its roots often immersed in water (*Conway 1949*).

In moderately moist situations, it is found with mountain maple, alder, meadow rose, and blackberries. It often invades grasslands, where it produces single, very large plants (*Stallard 1929*). Along forest margins, between forest and moist areas especially, it assumes an invader's role, as do hazel and gray dogwood. But where the latter two remain marginal, the red-osier dogwood soon extends into the moister regions.

LIFE HISTORY

Flowering occurs in May-June, but second flushes of bloom are common in late summer. The fruit, which is white to lead-color, ripens from July to early fall. The seed may germinate in the following spring or may lie over until the second spring.

Data are not available on the age for commercial seed-bearing (*U. S. Forest Service 1948*). The typical ages of first fruit-bearing, among unshaded or lightly shaded plants in Connecticut, were 4 years for wildlings and 3 years for nursery stock. Fruit yields were small compared to older plants (*Spinner and Ostrum 1945*). Little is known about geographic differences in seed production; however, in a species with such a wide distribution it is quite likely that differences exist.

Number of cleaned seeds per pound varies: 13,800 to 26,700 (*U. S. Forest Service 1948*) and 17,300 (*Van Dersal 1938*). The seed is heavy and is thus spread mostly by birds.

The species reproduces in a number of ways. As its specific name denotes, it produces stolons (runners). In a study in various habitats, this form of reproduction was noted primarily in very moist situations and in wet sedge meadows (*Smithberg 1964*). Reproduction also occurs from stems touching or growing under the ground, from seed, and even by shoot growth from roots. It was observed that when a branch is near death, a new branch may arise from the base of the old one. This occurrence accounts for the large many-stemmed forms often found.

Growth is fairly rapid. An average plant measured at the end of the first growing season, under clean cultivation, grew 443 inches of twigs (1,125 cm among all branches over three cm long) (*Smithberg and Weiser 1968*). The average plant height the first season was above 3 feet.

When found in meadows with close grass cover, the species tends to remain in single large plants, because layering cannot occur.

Light intensity no doubt plays an important role in limiting the spread of red-osier dogwood. It is suppressed in shade and thus is never a dominant understory plant (*Spector 1956, Stallard 1929*). Under shade conditions it often reaches a height of more than 10 feet.

USE BY WILDLIFE

The species is commonly browsed by deer (*Dahlberg and Guettinger 1956, Meagher 1958, Murie 1951, Smith 1964*). I noted in Minnesota that the species was preferred over gray dogwood when they were found growing together.

At Isle Royale in Lake Superior it is an important winter browse for moose (*Hosley 1949*). In Montana it is browsed extensively by elk, in winter, and by mountain goats (*Murie 1951*). Black bear and beaver include it in their diet (*Martin et al 1951, Rue 1964*), as do mule deer, cottontail rabbit, and snowshoe hare (*Van Dersal 1938*). Fruit, wood, and foliage are utilized.

Red-osier also provides food for many songbirds and upland game birds. In New England it was found in the diet of 93 different bird species (*McKenny 1933*). It is a favorite fall food of ruffed grouse (*Bump et al 1947*) and is one of the preferred foods of both pheasant and turkey (*Korschgen 1960*).

The fruits of the species are readily identifiable in stomach analyses because of the unique two-celled character of the nutlets.

Red-osier dogwood is an important cover species for birds. In a study of vegetation and animal use of power line rights-of-way, the species provided dense summer cover, and the winter stems provided partial cover (*Gysel 1962*). It is an important cover for pheasant (*Korschgen 1960*) and is commonly found near ruffed grouse drumming logs in lowland vegetation types (*Palmer 1961*).

In fishery management, red osier is recommended for streambank plantings to stabilize eroding banks and to provide shade and cooler water for summer protection of fish (*Black 1954*).

PROPAGATION

Plants of *Cornus stolonifera* are often available commercially. However, *Cornus alba sibirica*, a very closely related plant, is much more common. Some taxonomists feel that the two are one species, *Cornus stolonifera* on this continent being a geographic variant of the Eurasian *Cornus alba*.

Propagation is possible either from seed or cuttings, and each source can be handled in various ways. With seed, the first option is fall versus spring sowing. Though this choice will usually be made before seed collection, the collection, cleaning, and storage of seed should be about the same in either case. Fruits should be collected when fully ripe (late July-October), because plantings of immature seed have shown reduced germination. If viability testing is to be done, red-osier, along with other dogwoods, requires use of embryo excision, tetrazoluim chloride, or other special cutting tests (*Heit 1967c*). Cutting-test results in the range of 80 to 92 percent have been reported (*Swingle 1939*).

Seeds should be cleaned and air-dried if they are to be stored. The yield of cleaned seed is 15 to 20 pounds per 100 pounds of fruit, and the number of cleaned seed per pound averages about 19,000 (*U. S. Forest Service 1948*).

Fall sowing can be done in September-October or earlier. If dry, the seeds should be soaked, at least, before planting (*Heit 1968*). Soil recommendations are given in the life history discussion above.

The spring planting option requires storing and stratifying the cleaned, dried seed. Storage in sealed glass containers at 34 to 38°F for 4 to 8 years produced good germination, after stratification. The seeds have an embryo dormancy, which can easily be broken by stratification in sand, peat, or a mixture for 90 to 120 days at 41°F (*U. S. Forest Service 1948*) or longer, 120 to 140 and up to 290 days at 32° to 50°F (*Chadwick 1935*, *Laurie and Chadwick 1931*).

Some lots of seed may have hard-coat as well as embryo dormancy obstacles to germination and may require mechanical scarification before stratification (*U. S. Forest Service 1948*). Hard seed that has not been scarified may not germinate until the second spring after planting (*Laurie and Chadwick 1931*). Germination-test results have ranged from 6 percent for untreated seed (*Swingle 1939*) to 76 percent for stratified seed (*Chadwick 1935*, *U. S. Forest Service 1948*).

In the nursery, seeds are usually sown in drills at the rate of 40 viable seeds per square foot and are covered with ¼-inch of soil. The beds are usually mulched with leaves or straw, which is removed at the first sign of germination (*U. S. Forest Service 1948*). In one case, the yield per pound of cleaned seed was 2,979 plants when seed was spring-sown after stratification for 155 days at 40°F (*Swingle 1939*). One-year-old stock is usually large enough for outplanting (*U. S. Forest Service 1948*).

Use of cuttings or layering are practical alternatives to propagation from seed. Both softwood and hardwood cuttings root satisfactorily (*Laurie and Chadwick 1931*). No treatment of the cutting material is necessary. Cuttings taken in early. August rooted 100 percent in 5 weeks. Hardwood cuttings taken in mid-April and immediately set in the field rooted 90 percent in 8 weeks (*Doran 1957*). A wholesale nursery in Minnesota takes hardwood cuttings either in the fall or spring, plants them in 1½ x 2-foot spacing in sandy loam beds, irrigates only when necessary, and obtains about 60 percent rooting. The cuttings are ready for transplanting after one growing season (*Gordon Bailey, personal communication*).

Although treatment is not essential, over 90 percent rooting was obtained in hardwood cuttings 6 to 8 inches long which were dipped in indole butyric acid (500 ppm in talc), planted in sand, and intermittently mist-sprayed (*Smithberg 1964*). Sand was a better rooting medium than peatmoss for potted cuttings of various dogwood species (*Vermeulen 1959*).

Layering is also a common practice. Branches are held to the ground with hooks and covered with loose soil. Rooting occurs after several weeks. A shoot rooted in this manner is merely cut from the parent plant and transplanted to the desired location (*Hartmann and Kester 1959*).

MANAGEMENT

The ease by which the species can be propagated and its fairly rapid growth on open moist sites makes it a desirable choice for streambank planting and wildlife cover adjacent to farm ponds (*Chapman 1947a*). It is also commonly used for windbreaks, gullies, and field and woodland border plantings (*Graham 1947*).

Planting trials in New York led to conclusions that red-osier can be used interchangeably with silky dogwood (*C. amomum*) in all but the driest sites. Red-osier fruited more abundantly and somewhat later than silky dogwood, but not enough later to provide winter food for wildlife. Most of the wildlife use of both species apparently was feeding by songbirds. Both species showed good survival and growth (*Smith 1964*).

Red-osier dogwood can be controlled by spraying mixtures (in either oil or water) of 2,4-D and 2,4,5-T. Mixtures of dicamba and either 2,4-D or 2,4,5-T have also been recommended.

ELDERS

AMERICAN ELDER, *Sambucus canadensis* L. Also called Blackberry Elder, Common Elder, Elder, Sureau Blanc, and Sweet Elder.

SCARLET ELDER, *Sambucus pubens* Michx. Also called Red or Red-Berried Elder, Stinking Elder, and Sureau Rouge.

D. Michael Worley
Ohio University
Athens

and

Charles M. Nixon
Ohio Department of Natural Resources
New Marshfield

RANGE

Both species occur throughout most of the Northeast. Scarlet elder is more widely distributed northward, from Newfoundland to Alaska, but becomes localized southward, notably in northern Ohio swamps and the Appalachian highlands of West Virginia and Kentucky. American elder ranges from Cape Breton west to Manitoba, and south to Georgia, Louisiana, and Oklahoma (*Braun 1961, Fernald 1950, Gleason 1963c*).

HABITAT

Each species grows under a variety of conditions so that one or the other is acclimated to practically all the extremes that occur in the Northeast. Scarlet elder is less adapted to warmer climates than American elder and southward becomes localized to the cooler uplands or swamp forests (*Braun 1961*).

Both species tolerate saturated soils. American elder usually occupies well-drained slightly acid soil (pH 5.5 to 6.0) bordering streams and in the adjacent bottomlands, but also grows on gray forest soils and muck (*Laurie and Chadwick 1931*). Horticultural varieties of American elder succeed best in rich, moist, sandy soils (*Judkins 1945*). American elder has been found growing up to 4,000 feet in the southern Appalachians (*Ritter and McKee 1964*).

Scarlet elder grows in circumneutral soils (pH 6.0 to 8.0) and is somewhat more tolerant of dry soils and somewhat less adapted to saturated soils than American elder. Scarlet elder is often found on rocky soils (*Hottes 1931*), and in the Adirondacks is usually found where mineral soil has been exposed (*Webb 1959*).

American elder ranges almost throughout the eastern deciduous forests (*Braun 1961*). In upland mixed, moist-site communities, it is associated with witch-hazel, maple-leaved viburnum, ironwood, spicebush, and hophornbeam, and is most commonly found in the early successional types. In bottomlands, willow, alder, sycamore, and elm are common associates (*Braun 1950*). In oak-hickory communities, American elder is associated with hazelnut, spicebush, wild hydrangea and coralberry; and in the oak-chestnut community with gray dogwood, rose, New Jersey tea, and grape (*Braun 1950*).

Scarlet elder is seldom found south of, or lower in elevation than, the beech-maple forest zone, and in the southern portions of the region is restricted to higher altitudes in this community (*Braun 1961*). Scarlet elder is also associated with the hemlock-white pine-northern hardwood communities. Shrub species found with scarlet elder in these forests include American fly honeysuckle, beaked hazel, hophornbeam, and winterberry (*Braun 1950*). In the beech-maple and spruce forests of the Appalachian highlands, striped and mountain maple, hobblebush, and winterberry are common shrub associates (*Braun 1950*).

LIFE HISTORY

Both species bear separate male and female flowers on the same plant. Flowers usually occur on second-year and older canes and are arranged in clusters of compound cymes. Scarlet elder flowers from April through May, and the fruits ripen from June through August. American elder flowers from late June into August, and the fruits ripen from late July into September. Seed dispersal occurs from July to October in American elder and June to August in scarlet elder (*Park 1942, U. S. Forest Service 1948*).

American elder usually bears seed on second-year and older canes, but horticultural varieties grown from seed will occasionally fruit the first year (*Ritter and McKee 1964*). In Connecticut, wildlings first bore fruit at 3 years of age (*Spinner and Ostrom 1945*). The life span of individual canes is 3 to 5 years (*Deam 1932*). No information is available on youngest or oldest seed-bearing age of scarlet elder.

Information about fruit production is sketchy. In West Virginia, both elder species were checked during four consecutive years. There were no crop failures, and 70 to 80 percent of the plants bore fruit. Among 19 plants of comparable sizes, averaging 0.40 to 0.47 inch dbh, American elder produced about five times as much fruit, by volume, as scarlet elder (*Park 1942*). Scarlet elder may have alternate light and heavy fruit crops, and may be more variable in fruit yield than American elder (*U. S. Forest Service 1948*).

Seed dissemination for both species is usually through ingestion by birds and mammals. Passage through pheasants inhibited seed germination of American elder, but passage through song birds increased subsequent germination (*Krefting and Roe 1949*).

Elders reproduce from seeds, sprouts, layers, and root suckers; but establishment in new areas comes mainly from seed. Once established, runners of both species tend to persist through vigorous resprouting (*Ritter and McKee 1964*). Seedling growth is rather slow during the first year; seedlings of American elder grew only 2 inches in 45 days (*U. S. Forest Service 1948*). After the first year, growth is rapid for individual canes of both species, often as much as 15 feet (*Ritter and McKee 1964*). Sprout growth is much more rapid than growth from seed, and is most rapid in the first year after sprouting. Mature plants average 3 to 10 feet in height.

American elder grows best in full sunlight; scarlet elder is more shade-tolerant (*Chapman 1947e*). Once established, both elders soon outdistance herbaceous competition. Thickets of both species are replaced by more shade-tolerant species during the later stages of forest succession, but individual plants and small runners will persist under a forest canopy.

USES

At least 50 species of song birds relish the fruit of American elder during summer and early fall, and at least 25 species eat the fruit of scarlet elder during the summer (*Van Dersal 1942*). Wild turkey, bobwhite, quail, mourning doves, ruffed grouse, and ring-necked pheasants also eat the fruit during late summer and early fall (*Martin et al 1951, Van Dersal 1938*) as do red squirrels, rabbits, woodchucks, foxes, opossums, skunks, chipmunks, whitefooted mice, and raccoons (*Chapman 1947e, Martin et al 1951*). White-tailed deer feed on twigs, foliage and fruit of both species during the summer (*Martin et al 1951*), and moose have been observed browsing scarlet elder (*Van Dersal 1938*). American elder rates higher on deer food preference lists from four northeastern states than on those for southern states. Samples of American elder, collected in Louisiana and North Carolina, had higher percentages of crude protein (leaves 18, stems 7, and fruit 14) than most other browse plants (*Hankla 1961*).

New growth of American elder contains a glucoside that is occasionally fatal to livestock (*Hankla 1961*) and may influence deer utilization of elder. In the northern Lake States, a clipping study of scarlet elder showed erratic responses to heavy clipping in November. Capacity of the plants to withstand browsing was about equal to that of red-osier dogwood and mountain ash. Elders should be only moderately browsed each year (*Aldous 1952*). Cottontail rabbits, woodchucks, and red squirrels have been observed feeding on the bark of common elder during fall and winter (*Martin et al 1951*).

Elders provide fair escape cover for wildlife; and American elder has been ranked outstanding, along with grape and bittersweet, as nesting cover for small birds (*Petrides 1942*). American elder is thicket-forming, but the foliage of individual plants is quite open and the stems are bare. Scarlet elder is less apt to form thickets and offers less cover. However, during summer, the partial shade under American elder promotes a dense ground cover of grasses and forbs that offers good loafing or feeding areas for broods of young pheasants and quail (*Chapman 1947e*). In Ohio, elder thickets in bottomlands are often used by ruffed grouse broods during summer. In northern Ohio, wintering flocks of mourning doves roosted in a mixture of elder, sumac, blackberry, and dogwood found in openings within a pin oak stand (*Hennessy and VanCamp 1963*).

Both elders have been recommended and used for wildlife purposes in landscaping home grounds and roadsides (*Curtis and Wyman 1933, Holweg 1964*). Elderberries, of course, are also attractive to makers of pies, jams, and wine.

PROPAGATION

Seeds or rooted cuttings are available commercially, particularly for American elder, but seeds are not usually utilized for commercial propagation (*Mahlstede and Haber 1957*). Wild seed can be harvested from July through September and should be collected as soon as fruits ripen. Commercial seed consists either of dried fruit or clean seed. Seed soundness and purity for American elder averaged 80 and 92 percent respectively. For scarlet elder, soundness averaged 97 percent and purity 98 percent (*U. S. Forest Service 1948*).

Fruit of American elder contains three to five one-seeded nutlets (*Krefting and Roe 1949*). Yields of cleaned seed per 100 pounds of fruit were 7 to 18 pounds for American elder (14 samples) and 4 pounds for scarlet elder (6 samples). Average numbers of cleaned seed per pound (14 samples) were 232,000 for American elder and 286,000 (6 samples) for scarlet elder; ranges were 175,000 to 324,000 and 192,000 to 377,000 respectively (*U. S. Forest Service 1948*). Cleaned and dried seeds of both species showed little or no loss in viability after nearly 2 years of storage in sealed containers at 41°F. Scarlet elder seed also retained viability for 1 year when stored in moist sand at 41°F (*U. S. Forest Service 1948*).

Seeds of both species exhibit variable degrees of hard-seededness and embryo dormancy. Scarlet elder is more difficult to germinate than American elder, but both require pretreatment for good germination during the first year. As preparation for spring sowing, seeds can be scarified with sulfuric acid for 10 to 20 minutes (American elder) or 10 to 15 minutes (scarlet elder), washed, and then prechilled at 36 to 40°F for 2 months (*Heit 1967a*). As an alternative to the acid treatment, a warm/cold stratification in moist sand was effective for American elder. The sequence was 60 days at 68 to 86°F alternating daily, then 120 days at 41°F. A longer period of cold stratification, 150 days, was less desirable because seeds began to germinate at 41°F after 120 days. Also, freshly collected seed showed less dormancy than seed from dried fruit (*Krefting and Roe 1949*).

Scarlet elder seed may germinate more uniformly if given a combination of the treatments above; acid scarification, 3 to 4 months of warm stratification, and 2 months of moist prechilling (*Heit 1967a*).

For late summer or fall sowing of fresh seed, acid treatment, as described above, should improve germination in the following spring. Untreated seeds sown in late fall ordinarily do not complete germination until the second year (*Heit 1967a*). Fall-sown seedbeds should be well mulched because freezing does not favor after-ripening and may kill seeds that have imbibed water (*Davis 1927*).

American elder seed can be sown in drills, 35 viable seeds per linear foot, and covered with ¼ inch of soil. Germination rates as high as 80 to 85 percent have been attained. Beds of scarlet elder seedlings should be given half shade (*U. S. Forest Service 1948*).

Elders can also be propagated from hardwood cuttings taken from vigorous 1-year-old canes. Cuttings should vary in length from 10 to 18 inches, include 3 sets of opposite buds, and be taken in the spring as soon as the ground can be worked (*Ritter and McKee 1964*). Cuttings may also be taken in the fall, placed in moist peat or sphagnum moss, and held in cold storage at approximately 40°F for spring planting (*Mahlstede and Haber 1957*).

One-year-old seedlings or rooted cuttings of both species are usually large enough for field planting (*U. S. Forest Service 1948*). American elder should be planted in moist, rich, slightly acid soil, preferably in low swampy areas in a sunny location. No information is available about success of direct-seeding or the pretreatment of planting areas. If herbaceous growth is rampant, scarification should improve seedling survival. Scarlet elder is more tolerant of shade and soil conditions and may be planted on a variety of sites. However, in the southern portions of the Northeast, scarlet elder may not succeed at lower elevations or away from the beech-maple community (*Braun 1961*).

MANAGEMENT

Elders may serve best as nesting cover and a summer and early fall food source for birds. American elder seems superior to scarlet elder for such purposes, but is more demanding in its site requirements. Mixtures of the two species may be desirable, particularly where the site is partly shaded or the soil is less moist than that preferred for American elder. Mixtures are also recommended for contrast in decorative landscape plantings—particularly as tall background shrubs in fairly moist, partly shaded locations (*Curtis and Wyman 1933*). Pond and stream margins are among the best locations for both species (*Chapman 1947e*).

American elder can be used, at least partly, for erosion control on moist sites. It pioneers on some strip-mine spoils and may occasionally be useful for reclamation planting (*Chapman 1947e*).

Experience with cultivated varieties of American elder has shown that annual pruning will considerably improve fruit yield. Pruning should aim to leave five to six strong, 1-year-old canes and one or two older canes per runner. Removal of terminal shoots and dead canes will reduce winter-kill of terminal shoots and help control elder borers (*Ritter and McKee 1964*).

Both species fruit best in full sunlight, although scarlet elder will produce some fruit under a fairly dense canopy. Shading should be controlled if maximum fruit production is desired. Once established, the elders seem to outdistance herbaceous competition.

For wildlife management purposes, elders would seldom need to be killed; but they are susceptible to control by AMS or 2,4,5-T. They are intermediate in susceptibility to 2,4-D, and resistant to Amitrol, diuron, fenuron, and monuron (*Dunham 1965*).

SUMMER GRAPE

Vitis aestivalis Michx. and
Vitis aestivalis var. *argentifolia* (Munson) Fern.

Also called Blue, Bunch, Pigeon, and Silverleaf Grape.

By Lynn M. Shutts
USDA Soil Conservation Service
Moorefield, West Virginia

RANGE

Summer grape (including the variety *argentifolia*) ranges northward as far as southern New Hampshire to southern Minnesota—but not into Canada—and southward to Georgia and Texas. It is uncommon near the northern limits of its range. In West Virginia, summer grape is the most common grape species, and the variety *argentifolia* is nearly as abundant as the typical form (*Fernald 1950, Massey 1961, Strausbaugh and Core 1958*).

HABITAT

The optimum climatic conditions for summer grape have not been described, but grapes are subject to both cold and heat injury. A sudden temperature rise in late spring may result in damage to shoot tips. Spring frosts often damage foliage if warm weather and rapid growth precede a sudden temperature drop. Grapes do best under the moderately moist conditions necessary for adequate growth and resistance to disease. The primary damaging effect of excess moisture (rain or high humidity) is the enhancement of fungous diseases that destroy the fruit.

This species is generally restricted to upland areas (*Hedrick 1908*). The vines do well on light, easily crumbled, shallow soils of old formation (*Viala and Ravaz 1903*). In Virginia, summer grape was found growing over a wide range of soil and site conditions (*Shutts 1968*). The pH requirements are variable.

Vines often occupy moist bench areas or ravines on southeastern slopes where organic matter has accumulated. Common associates are those species that occupy cove sites. Individual vines have been observed climbing in practically all species of hardwoods and conifers that occur within the range of summer grape.

LIFE HISTORY

The species bears male and female flowers on separate plants, and the flowers bloom from May through July. Pollen is disseminated by wind and rain. The fruit ripens to a dark purple in September or October (*Massey 1961*). Seeds are disseminated by wind action and by animals.

The plant is capable of producing seed the third season after establishment. The fruit crop is variable and often fluctuates greatly from year to year, but good crops occur in most years. Six vines with diameters ranging from 0.8 to 2.1 inches produced a total of 9,-

334 individual grapes in one season. Approximately 40 percent of these grapes were affected by black rot fungus, which reduced their food value. The number of bunches per vine increased with the diameter of the vine (*Shutts 1968*). Dropping of fruit from the vines peaked during the first 2 weeks of November in the Ridge and Valley Province of Virginia (*Shutts 1968*).

Grapes may reproduce by means of seeds, sprouts, or layers. Terminal growth is very rapid, but lateral growth is slow. A vine 50 years old may have a diameter at ground level of only 1.5 inches.

The effects of sunlight on establishment are unknown. However, woodland openings, such as those produced by windfall or logging, appear to accelerate growth.

USE BY WILDLIFE

Black bear, raccoon, bobwhite quail, ruffed grouse, wild turkey, and a host of song birds eat grapes (*Martin et al 1951*). Deer browse the foliage and stems in the spring and early summer, and may consume large quantities of fallen leaves during the winter months (*Massey 1961*).

In summer, grape stands provide excellent escape and nesting cover for song birds. The vines may be so twisted and tangled as to effectively exclude predators.

Birds often use the stringy bark in nest construction (*Martin et al 1951*). Gray squirrels also build leaf nests with grape vine bark, and trees with grape vines in them appear to be preferred sites for leaf nests.

PROPAGATION

Seed is not available commercially, but may be collected in fruit traps made of polyethylene (*Shutts 1968*). Seed collection may be accelerated by shaking the bunches from the vines during late October and early November. During years of heavy fungus attacks, seed may be only 50 percent sound.

Grape seeds are not difficult to germinate, but plants raised from seeds may not be true to type (*Hartmann and Kester 1968:384; Hosley 1938:339*). Seed should be cleaned, stratified over winter, and planted in early spring. Good results have been obtained with a commercial species (*V. vinifera*) after a moist stratification period at 33 to 40°F for about 12 weeks before planting (*Hartmann and Kester 1968:385*). After 1 year in seedbeds, seedlings can be transplanted to permanent locations (*Massey 1945*).

Probably the most effective method of propagation is layering in early spring, because this produces new plants of known sex. Plantings should have at least one male plant for every three or four female plants (*Massey 1961*). Cuttings are low in rooting efficiency (25 percent). Grafting can be used to increase fruiting vines or pollen-producing vines where an improper balance is evident (*Massey 1945*).

MANAGEMENT

Summer grape is well adapted to grow in a variety of special situations such as over stone walls, rock piles, fences, spoil banks, or up over trees of poor quality (*Hosley 1938:337*). It could be used in most forest situations where production of wildlife food and cover were of primary importance. Grape stands may be effective in concentrating turkeys and grouse for harvest because the peak of fruit fall usually occurs in early November.

The best methods of maintaining grape stands are not yet known, but U. S. Forest Service studies about maintenance of grape stands have been initiated on the Jefferson National Forest, New Castle, Va. Grapevines are best controlled in large timber by severing the vines at their base. In small timber the herbicide 2,4,5-T can be applied as a foliage spray.

GREENBRIERS

COMMON GREENBRIER, *Smilax rotundifolia* L. Also called Bamboo-Brier, Biscuit-Leaves, Bread and Butter, Catbrier, Common Bullbrier, Devil's Hop Vine, Horsebrier, Hungry Vine, Roundleaf Greenbrier, Sowbrier, and Wait-a-Bit.

CAT GREENBRIER, *Smilax glauca* Walt. Also called Catbrier, Glaucous-Leaf Greenbrier, Sawbrier, Sarsaparilla Vine, and Sowbrier.

WITH NOTES ON

SAW GREENBRIER, *Smilax bona-nox* L.

LAUREL GREENBRIER, *Smilax laurifolia* L.

By Robert L. Smith
West Virginia University
Morgantown

RANGE

Eleven species of greenbrier occur in the eastern United States and Canada, but most grow primarily in the South; and only four species are considered here.

Common greenbrier is widely distributed throughout the East, from Nova Scotia to southern Ontario and Illinois, south to Florida and Texas. It is most common in the northeastern part of its range (*Gleason 1963*).

Cat greenbrier, the second most common species, has a more southern distribution, the northern edge of its range reaching into southern New England and New York, eastern Pennsylvania, and southern Ohio (*Fernald 1950*); it is most common in the southern part of its range (*Gleason 1963a*). Bristly greenbrier is widespread in the Northeast, but is seldom abundant and is not discussed here because little information about it was available.

Saw greenbrier is chiefly a southern species that extends northward along the coast to Maryland and Delaware. Laurel greenbrier, an evergreen, is primarily a coastal species in the Northeast, occurring only along the coasts of Virginia, Maryland, and New Jersey (*Fernald 1950*).

HABITAT

The greenbriers are adapted chiefly for southern climates. In the North they are found principally on warmer and drier west- and south-facing slopes. Common greenbrier is the most common species in the Northeast; it grows on a wide range of sites from moist to well-drained to dry, although in the south it is most abundant in low, damp flatwoods (*Goodrum 1961*). The optimum soil pH was reported as 5.0 to 6.0 (*Spurway 1941*). Cat greenbrier and saw greenbrier grow in a variety of soils and moisture conditions (*Goodrum 1961*), but in the Northeast cat greenbrier is characteristic of dry, well-drained soils (*Braun 1950*). In the highly dissected mountains of southwestern West Virginia, common greenbrier is widely distributed on south slopes and grows over the ridgetops and onto upper north slopes, but cat greenbrier is confined to south-facing slopes (*W. A. Van Eck and R. L. Smith, unpublished data*). Laurel greenbrier occurs mostly in low, wet grounds and swamps. It is most abundant in the bogs and pocosins near the coast from New Jersey to Florida (*Oosting 1956*).

Both common and cat greenbrier are pioneering successional species as well as components of forest understory vegetation. They commonly invade old fields, where they may be associated with sumacs, St. John's wort, black locust, sassafras, blackberry, blueberry, and bracken fern; and they remain a part of the understory when forest claims the site. Common understory associates are witchhazel, mapleleaf viburnum, grape, and flowering dogwood (*R. L. Smith, unpublished data*).

Although most greenbriers grow well in the shade, they generally do not grow or mature as rapidly, or produce as much fruit, as plants in the open (*L. K. Halls 1968, unpublished report*). Common greenbrier is more shade-tolerant than cat greenbrier, and good fruit crops have been noted in West Virginia for common greenbrier in 70 to 80 percent shade. Both species usually achieve maximum growth and produce the most fruit along the forest edge and in forest clearings where better moisture conditions may compensate for shading, or in old fields where they may cover the ground with dense spiny tangles. In Texas, young common and saw greenbrier plants yielded 11 or 12 times more browse in the open than in heavy shade from pines (*L. K. Halls 1968, unpublished report*). No such data for intermediate levels of shading are available; but in the Northeast, common greenbrier, at least, grows better than cat greenbrier in partial shade. Shading of about 10 to 20 percent may be optimal for common greenbrier.

In the woods, common and laurel greenbrier tend to climb into trees. In the Northeast, common greenbrier rarely overburdens the supporting trees, and it seldom interferes seriously with tree or shrub regeneration. Cat greenbrier, however, often dominates other woody vegetation in old fields.

LIFE HISTORY

The greenbriers are climbing vines supported by tendrils that grow in pairs from the axils of the leaf. The male and female flowers, small and greenish yellow or white, are borne in small clusters on separate plants. In the Northeast, common and cat greenbrier bloom in May and June, and saw greenbrier from May to July. Laurel greenbrier flowers later, August and September, and its fruit does not ripen until October of the following year (*Fernald 1950, Gleason 1963a, Van Dersal 1938*).

The fruits of common, cat, and saw greenbrier ripen during September and October, the first year, into black berries covered with a whitish bloom. The fruit of common greenbrier usually contains 1 or 2 seeds, but may have 4. Cat greenbrier fruit may also have 0 to 4 seeds but usually has 1 to 3 (*F. L. Pogge, unpublished data*). In Connecticut, cat greenbrier fruited first at age 2 years among wild plants and at 1 year in nursery-grown vines (*Spinner and Ostrom 1945*). The canes, which live for 2 to 4 years, produce flowers after the first year, usually on the annual shoot growing from the upper part of the cane (*Goodrum 1961*). Fruits usually persist on the vines into the winter (*Park 1942*). Cat and common greenbrier fruits often persist until the next summer.

The fruits of common and cat greenbrier consist of about equal weights (oven-dry) of fruit pulp and seed (*L. K. Halls 1968, unpublished report*). Chemical analysis percentages for seed collected in Rhode Island and air-dried were, for common and cat greenbrier respectively: protein 9, 11; fat 5, 8; crude fiber 19, 18; nitrogen-free extract 61, 57; ash 3, 3; and water 3, 4 (*Wright 1941*). Leaves and browse-stems of common greenbrier collected in North Carolina, Maryland, and Louisiana have been similarly analyzed. Crude protein percentages ranged from 7 to 16 percent and varied with season and site factors as follows:

Higher	Leaves	Spring	Burned site	Open site
Lower	Twigs	Fall	Unburned	Woods

Fat content was generally low, 2 to 4 percent, except for one sample (6.1 percent) of leaves from Louisiana (*Blair and Epps 1969; DeWitt and Derby 1955; Halls and Epps 1969; Smith et al 1956*).

Although greenbriers reproduce by seed, common, cat, and saw greenbriers spread most rapidly by means of underground stems. The underground stems of saw greenbrier bear woody tubers growing singly or in clumps up to 6 inches across. Cat greenbrier has tubers and rhizomes, the latter possessing small prickles between the nodes. Common greenbrier lacks tubers, but has long, slender underground stems. Laurel greenbrier has hard and thickened tubers, but lacks true stolons (*Vines 1960*). These underground stems usually produce new canes annually, and the canes grow quickly.

Nearly all the annual growth of greenbrier stems is completed in a relatively short time. In Texas, common greenbrier started growth in early April, and 90 percent of the growth was complete by 1 May for plants in pine woods and by 20 May for plants in the open. Plants under the pines consistently started growth about 3 to 6 days earlier than those in the open. Mean length of "browse twigs" was 40 percent greater in the open than in the woods—probably representing a real but not statistically significant difference (*Halls and Alcaniz 1972*). There may be some dieback in late summer and fall (*Halls and Alcaniz 1965b*). Clipping and browsing stimulate production of new shoots; up to 60 percent of greenbrier annual growth can be browsed without injury (*Schilling 1938*). Even when all the new monthly growth was removed, common and laurel greenbrier were highly tenacious species in Texas (*Lay 1965a*).

Common and laurel greenbrier sometimes form almost impenetrable spiny thickets. Saw and cat greenbrier are more open and straggling in their growth form, but cat greenbrier often forms dense low tangles in old fields.

USES

Of all vines and shrubs in the Northeast, few if any outrank the greenbriers for wildlife food and cover. The fruit of greenbrier is eaten by at least 38 species of non-game birds (*Martin et al 1951*), such as the catbird, crow, mockingbird, thrasher, robin and other thrushes, white-throated sparrow, phoebe (*Hausman 1931*), and pileated woodpecker (*Hausman 1928*). Common greenbrier and cat greenbrier are important in the winter diet of ruffed grouse, especially in the central and southern Appalachians (*Gilfillan and Bezdek 1944; Nelson et al 1938*) and are taken in the same area by the wild turkey (*Bailey and Rinell 1968, Martin et al 1939, Mosby and Handley 1943*). Greenbrier fruits are also eaten by sharp-tailed grouse, prairie chickens, and ring-necked pheasant (*Van Dersal 1938*). Greenbrier seeds may also serve as grit for game birds.

Greenbriers are among the most important deer browse plants, especially in the southern and central Appalachians, where they are utilized throughout the year (*Blair and Halls 1968, Dalke 1941, Goodrum 1961, Lay 1969, Ripley and McClure 1963*). The greenbriers are highly palatable to deer (*Halls et al 1957, Halls et al 1969*), and are exceptionally succulent. Even in fall the twigs contain no more than 32 percent dry matter. And greenbrier browse is relatively high in protein. Deer require a daily protein intake of 13 to 16 percent (dried weight) for growth, and 7 percent for maintenance (*Magruder et al 1957*). The leaves of greenbrier provide sufficient protein for animal growth during the early flush of plant growth in the spring (*Blair and Halls 1968*), and the twigs contain sufficient protein for maintenance in spring (*Blair and Epps 1969*). Protein levels decline steadily throughout the summer, but remain above the amount needed for maintenance until the leaves fall.

In winter the twigs supply, or nearly supply, the needs for maintenance. Laurel greenbrier, since it is an evergreen and leaves are available as browse through the year, adequately supplies maintenance requirements of deer; and the twigs of common greenbrier may also meet maintenance needs during winter. Twigs of common greenbrier collected in Maryland contained over 10 percent crude protein in winter (*DeWitt and Derby 1955*), and twigs collected in North Carolina contained over 13 percent crude protein in winter (*Smith et al. 1956*). Twigs of common greenbrier collected in Louisiana, however, contained only 7 percent crude protein in winter (*Blair and Epps 1969*). Like most woody browse species, greenbriers contain adequate amounts of calcium, but are deficient in phosphorus (*Blair and Epps 1969*).

Greenbriers also withstand and respond well to heavy browsing. Up to a point, the more the canes are browsed, the more additional growth they add. Thus, palatability, nutritional quality, and availability make greenbriers important in the management of white-tailed deer in the Northeast as well as in southern United States.

Rabbits also browse the leaves and twigs of greenbriers, especially those of common and cat greenbriers (*Blair 1936 Trippensee 1938*).

For covering tree stumps, trellises, etc., and for an inpenetrable fence along property boundaries, horticulturists suggest the common greenbrier as a desirable species (*Everett 1960, Taylor 1948*).

Native North Americans and early pioneers used the roots of some greenbriers as food. They pounded the roots to a pulp, washed them in water, strained this, and allowed the sediments to dry into a fine reddish powder. This powder, after boiling in water, produced a jelly-like pudding. The meal was also used to make bread or cakes, fried in bear grease, and to thicken soups (*Gibbons 1970*). The young shoots of the four greenbriers discussed can be eaten raw as a salad or cooked like asparagus tips. Greenbrier extract was once used as a mild diuretic.

PROPAGATION

Because it is generally considered a nuisance, much more emphasis in the literature is placed on the eradication of greenbrier than on its propagation (*Fernald 1950, Strausbaugh and Core 1952, Taylor 1948*).

A recommended method of propagation is to divide and plant the roots in spring. The soil should be firmed about the roots and kept thoroughly moistened (*Everett 1960*). Canes may not appear from the rootstocks until the second year (*Goodrum 1961*).

Some greenbriers can also be propagated from stem cuttings. In Texas, cuttings about 6 inches long were taken in May when the twigs were actively growing and the leaves were fully expanded, in September when the growth was over and the wood was partially matured, and in January (*Halls and Alcaniz 1965a*). All leaves except two terminals were removed from each stem; the cut ends were dipped in a solution of indolebutyric acid, set upright to a depth of 2 inches in a 3 to 1 mixture of sand and peat, and the cuttings were shaded 30 percent and mist-sprayed regularly. Rooting success was 55 percent for common greenbrier. Saw greenbrier rooted erratically (32 percent), cat greenbrier rooted poorly, and laurel greenbrier did not root at all. Cuttings taken in May generally rooted better than those taken in September, but the latter month is better suited to out-planting in the spring (*Halls and Alcaniz 1965*).

Greenbriers can be propagated from seed, but optimal procedures are unknown. Howard (*1915*) obtained 51 percent germination of common greenbrier seed in 38 days. The seeds had been cleaned, dried, and stratified outdoors over winter, during which time they were exposed to freezing. Common and saw greenbrier seed in Texas responded well to cleaning and stratification in moist sand at 40°F over winter. Seeds were planted in early spring and lightly covered with soil. Seedlings were ready for transplanting after 1 year in the nursery (*Lowell Halls 1970, personal communication*).

Fruit and seed data supplied by Franz L. Pogge for 52 samples of common greenbrier and 35 samples of cat greenbrier collected at various sites near Morgantown, West Virginia were:

Item	*Common greenbrier*	*Cat greenbrier*
Fruit size, inches	1/8 7/16	3/16-7/16
Seeds per fruit:		
Usual number	1-2	1-3
Range	0-4	0-4
Sound seed, average	1.33	1.90
Seed soundness, percent*	51-89	74-94
Fruits per pound, average	1,825	1,550
Sound seed/pound fruit:		
Average	2,425	2,950
Lowest	1,600	2,050
Highest	3,750	3,525
Clean sound seed/pound, average	9,225	9,775

*Exluding one aberrently low sample for each species.

In current studies (*July 1972*) by the Northeastern Forest Experiment Station, common greenbrier was fairly easy to propagate from seeds, stem cuttings, and root cuttings, but cat greenbrier showed promising results only from tubers collected while dormant (*Franz Pogge, personal communication*).

MANAGEMENT

Greenbrier grows in partial shade, in the open, and on a variety of soils. However, maximum growth of twigs and production of fruit is usually obtained from plants in the open. This suggests that a major management practice should involve release of vines from overhead shade. This would increase fruit production and the quantity and quality of browse.

When canes become too tough or grow out of the reach of deer, new growth can be stimulated by cutting or disking, and by prescribed burning (*Goodrum 1961, Lay 1956*). The underground stems are highly resistant to fire, and new shoots develop quickly (*Lay 1956*). Prescribed burning increased both forage production and protein content of common greenbrier. High-intensity fires produce the highest quality browse. Protein content of browse increased 8 percent after low-intensity fire, and 19 percent after a high-intensity fire (*DeWitt and Derby 1955*).

Eradication or control of greenbrier by cutting is usually ineffective. Individual plants may be eliminated by digging out the roots; but for species as aggressive as greenbrier, this may be impractical. Cat greenbrier has proven rather difficult to control by herbicidal sprays. It is moderately to completely resistant to granular borate TBA applied at the rate of 275 to 400 pounds per acre (*Woestemeyer 1963*), and to fenuron at the rate of 16 pounds per acre (*McCully 1958*). Effective control of greenbrier was obtained by foliar and stem sprays (in water) of 2,4,5-T at 2 pounds acid equivalent per acre (*Elwell 1961*). Common greenbrier was controlled (kill of 95 percent) by spraying with 2,4-D plus 2,4,5-T in oil at 1 to 20 in 1 part oil and 3 parts water applied to the stems and foliage in July (*Niering 1961*). Saw greenbrier was rated susceptible to AMS only, among 9 herbicides (*Dunham 1965*).

HAWTHORNS

Crataegus L.

Also called Cenellier, Haw, Pommettes, Red Haw, Thorn, Thorn-Apple.

By Ward M. Sharp
USDI Bureau of Sport Fisheries and Wildlife
Warren, Pa.

SPECIES

Hawthorns comprise the largest single group of shrubs and small trees in the Middle Atlantic States and Northeastern States and Provinces. Because of the hawthorn's complex nature, the genus is divided into 19 series; and species representing 17 of these series occur in the Northeast. Regional floras or manuals are recommended for identification of the hawthorns. "The Illustrated Flora of the Northeastern United States and Adjacent Canada" (*Gleason 1963c*), and "The Flora of West Virginia" (*Strausbaugh and Core 1953*) are particularly helpful because of their illustrations in addition to the keys.

Hawthorns are medium to tall shrubs, 5 to 25 feet in height, with round, dense crowns in some species; crowns of other species are generally cylindrical or conical. Upon close-up inspection, hawthorns are distinguished by the presence of straight or slightly recurving, smooth, hard thorns on the woody branches; and sometimes additional multi-branched thorns on the larger main stems. The presence of stout thorns is a year-round characteristic that distinguishes hawthorns from other shrubs and small trees. The sweet crab apple [*Malus coronaria* (L.) Mill.] is often mistaken for a hawthorn, but the short thorns in the crab apple arise from the apex of a short, leaf-bearing, spur-like branch.

After mid-August, the small, berry-like fruits of most hawthorns turn reddish to red. Only a few species have yellow or yellowish fruits. The later-ripening species retain their fruits after leaf drop; and, in years of heavy crops, the red fruits impart to the crown a reddish tint that serves as a further distinguishing mark in this season of the year. The red fruits of the deciduous hollies, especially common winterberry [*Ilex verticillata* (L.) A. gray], also impart a reddish tint in their crowns in autumn.

RANGE

Hawthorns occur throughout the Northeast in pastures, in fence rows on farms, and on idle lands in rural areas. Western sections of Pennsylvania and New York, for example, have a rich hawthorn flora, both in numbers of species and abundance in local areas. Hawthorn abundance is associated with areas where farms were operated for livestock as well as row crops. In areas where row crops prevailed, hawthorns are uncommon; but, in localities where grazing of livestock was important, hawthorns are common to abundant. In the coastal and piedmont provinces of the region and in the sprawling megalopolis, intensive clean farming and the abundance of eastern redcedar (*Juniperus virginiana* L.) have limited the hawthorns' distribution and abundance.

HABITAT

Hawthorns are well adapted to the climate of the Northeast. Ohio, Pennsylvania, and New York have the greatest array of species; at least 60 percent of all species in North America may occur in these states. Hawthorns are both cold-hardy and drought-hardy except in the flowering period, when the female flower-parts (styles and stigmas) are vulnerable to frost.

The numerous species of hawthorns are adapted to a broad range of soil types, ranging from fertile calcareous soils to acid soils of sandstone origin and low N-P-K content. Hawthorns generally prefer moist or well-drained sites, especially the latter; but sites water-logged in spring support a number of species.

Hawthorns require full sunlight for optimal growth. They are intolerant of shading, and wane and die off when overtopped by a tree canopy. Being tall shrubs, they convert open grassland to a savanna-type community where grasses and forbs are continuous in the ground layer and the tall hawthorn shrubs are scattered throughout the site.

A unit of area populated by hawthorns is defined here as a stand. In Pennsylvania, stands occupied by hawthorns varied in size from 1 to 60 acres, with an average of about 4 acres (*Hoover 1961*). Past land-use practices determine the development of hawthorn stands. Land grazed by livestock favored hawthorn invasion and development. Cows relished the ripened fruits and disseminated the bony seeds in their dung, which nurtured the hawthorn seedlings and aided their establishment in sodded areas. Grazing by livestock prolongs the life of a hawthorn community.

The hawthorn stand is also a rich site for other shrubs and brambles. Such shrubs as sweet crab apple, sumacs, dogwoods, juneberries, and blueberries occur in these communities. Old-field species of blackberries (chiefly those of the section Arguti) may develop clonal colonies.

Abandoned lands that were previously used for livestock operations are more productive of hawthorns than those used for row crops. But in the absence of grazing, trees usually invade and finally engulf the open land. Common tree invaders are those whose seeds are disseminated by the wind—ash, maple, elm, and pine. Black cherry also invades where seeds are brought in by birds. By repelling browsing animals, hawthorns protect other seedlings that grow up through them, and these invaders eventually shade out the hawthorns and dominate the site. Hawthorns—to their own detriment—are excellent nurse crops for invading trees.

LIFE HISTORY

In Pennsylvania, early flowering species generally begin blooming about May 5, and later flowering species come into full bloom in the first 10 days of June (*Hoover 1961*). Flowering dates are not identical from year to year because of annual variations in spring temperatures. Because the flowering period of different species extends over a month, late spring frosts would affect only those species in flower at the time of a freeze. In stands with only early-flowering species, for example, an early May frost could eliminate the fruit crop.

The fruits of early-flowering species ripen in late August, while those of late-flowering species ripen after mid-September. Fruits of early-ripening species have soft, pulpy flesh and do not have lasting qualities. Those ripening after mid-September have firm, fleshy fruits. Fruits of some of the latter species, upon falling to the ground and being covered by leaves or grass, remain firm into the following spring.

Seeds of hawthorns are hard, bony nutlets. When fruits are eaten by mammals or birds, only the pulp is digested, and the seeds pass through the alimentary tract. There are exceptions, of course, such as cud-chewing mammals or the larger game birds with gizzards efficient in grinding. Deer pass few seeds, if any, but cattle pass numerous seeds in their dung. In ruffed grouse, the bony seeds appear to serve as grit, but many are found intact in droppings.

Hawthorns are propagated in nature by seeds. Three factors have been considered important for regeneration: availability of seeds, suitable germination conditions, and survival of seedlings (*Hoover 1961*). Hawthorn seedlings most commonly establish in grasslands. Best survival is in recently abandoned cow pastures or where grazing is light. Seedlings are unable to establish themselves in full shade.

Hawthorns may grow from a single stem, or two or more may arise from a base. The latter form is often the result of rabbit browsing in the seedling stage or crowding of plants growing side by side. Frequently two or occasionally three plants of different species may arise together, their crown branches forming what appears to be a single shrub. This trait can be confusing in species identification.

Once hawthorns attain about 2 feet in height, the sharp thorns in the compact crown, if hedged from previous browsing, create a barrier to livestock and deer. Cottontails may inflict heavy browsing on seedlings about 6 to 24 inches in height, but rabbits avoid taller plants as a rule.

Since hawthorns are shade-intolerant, they cannot compete with faster-growing trees or tall shrub regeneration that overtops or crowds the sides of the crown. In particular, the spreading, vigorous crowns of sweet crab apple often crowd and weaken hawthorns by shading the sides of their crowns.

INSECTS AND DISEASES

Hawthorns are subject to attack by both insects and diseases. Based on my hawthorn research, those species with thick, leathery leaves are the most resistant, while those with leaves of thin texture are the most vulnerable. Insect infestations are, as a rule, periodic and local. But the troublesome diseases may be an eliminating factor unless the source of infection is eradicated.

Several groups of insects attack hawthorns (*Hoover 1961, Johnson et al 1966, Wiegel and Baumhofer 1948*). Field studies indicate that the hawthorn lacebug (*Corythucha cydoniae*) and the wooly aphid (*Eriosoma crataegi*) inflict the most damage over extended areas in Pennsylvania (*Hoover 1961*). Infestations of lacebugs destroy the chlorophyll by August, leaving the leaves brown and sere. Wooly aphids attack the branches en masse, probe into the cambial layer, and girdle or kill branches along one side.

Defoliating insects known to feed on hawthorn leaves are the tent caterpillar (*Malacosoma americana*) and the fall cankerworm (*Alsophila pometaria*). Outbreaks of the cankerworm are periodic, and only one severe attack on hawthorns was observed in Pennsylvania over a 16-year period. This infestation coincided with a regional irruption occurring across northern Pennsylvania during 1966 to 1968. Atfer two successive years of complete defoliation, hawthorns became weakened and top dieback was prominent.

The hawthorn leaf-aphid (*Anuraphis crataegifoliae*) is a pest (*Wiegel and Baumhofer 1948*) that seems to cause only minor damage while leaves are succulent. I observed local damage to hawthorn stands by the seventeen-year cicade (*Magicicade septendecim*) in Pennsylvania. The female cicadas damage hawthorns when slitting the branches in the act of laying eggs. Their damage is local because of isolated nature of the outbreaks. The long interval between attacks permits the shrubs to recover.

Two rusts of the genus *Gymnosporangium*, two leafblights (*Fabraea maculata* and *Entomosporium thuemenii*), and fireblight (*Erwinia amylovora*) were reported as causing disease in hawthorns (*Johnson et al 1966, Strong 1960*). But these blights were not encountered on native species of hawthorns during field work in Pennsylvania (*Hoover 1961*). The English hawthorn (*Crataegus oxycantha* L.), its horticultural cultivars, and other exotic species are the principal targets for these blights (*Inman 1962, Nichols 1958, Strong 1960*).

Two eastern redcedar/hawthorn rusts, (*G. clavipes* and *G. globosum*) parasatize hawthorns. Of all the diseases, the hawthorn rust (*G. clavipes*) is the most destructive, infesting the leaves, fruits, and branches (*Hoover 1961*). The eastern redcedar is the alternate host of these rusts. Wherever redcedar occurs, one can expect to find either heavily infested hawthorns, the remains of those that are dying out, or no hawthorns in the area. The cockspur hawthorn (*C. crusgalli* L.) with thick leathery leaves, is one of the few native species whose leaves resist rust. Leaves of the series Rotundifoliae, which also are thick, resist damage. But the fruits of the above-mentioned hawthorns are damaged or eliminated by these rusts.

The control of diseaes and insects infesting hawthorns requires comment. Attempts to eliminate rusts and leaf blights or hawthorns by use of chemical fungicides have been unrewarding (*Chapman and Schneider 1955, Strong 1960, Nichols 1958, Strong and Klomparens 1955, Inman 1962*). Applications of fungicide sprays were time-consuming and expensive; and results were temporary. The only permanent solution for the control of hawthorn rusts is to cut the infested redcedars. Several species of junipers are resistant to cedar rust (*May 1965*). These rust-resistant species should replace the redcedar in future estate and landscape planning. But the problem of values between established stands of hawthorns and redcedars becomes controversial when multiple land ownership is involved.

Leaf blights prove troublesome only among the exotic cultivars such as English hawthorn. Based on my extended field studies of hawthorns in Pennsylvania and New York, the native hawthorns are resistant to leaf and fire blight. Since insect infestations are periodic and local in nature, use of insecticides may prove more harmful to the total hawthorn community than the impact of insect outbreaks.

USES

The fruits of hawthorns are consumed by a number of birds and mammals, including upland gamebirds and songbirds, fur and game animals, and deer and cattle (*Chapman 1947b; Martin et al 1951*). The occurrence of hawthorn fruits in food studies varies partly because year-to-year yields are inconsistent. There may be good to bumper yields in a particular year, only to be followed by 1 or 2 years of poor yields.

A review of food studies of ruffed grouse in the region reveals that hawthorn fruits are a key item in their fall diet. The fruits are eaten by wild turkeys, beginning with the early-ripening species in August. A recent statewide study of white-tailed deer foods in Ohio showed that the fruits and leaves of hawthorns ranked 14th as a preferred food item (*Nixon et al 1970*). Cottontails feed on the fallen fruits, and songbirds utilize the fruits adhering to the branches in winter.

The leaves and succulent shoots of hawthorns provide palatable forage for deer and cattle. Heaviest use occurs in May and June, when shoot tips are succulent. Under heavy browsing, plants are hedged to 5 feet above ground. Cottontails browse seedlings under 2 feet in height throughout the year. Hawthorn use by cottontails in Michigan closely approached that of apple which was a highly preferred winter browse (*Trippensee 1938*). My recent study on the impact of browsing in a savanna community in northwestern Pennsylvania revealed that 85 percent of all hawthorns under 5 feet in height were browsed by deer or by cottontails.

Hawthorn stands serve as special habitat niches for upland wildlife. They are important brood-rearing areas for ruffed grouse and wild turkeys (*Sharp 1965*), and they form excellent woodcock coverts (*Liscinsky 1963*). In Ohio, abandoned fields reverting to hawthorns, sweet crab apple, and shrubby dogwoods—all staple deer foods—provide deer with their most productive feeding areas (*Nixon et al 1970*).

Hawthorns provide nesting sites for several species of birds, including brown thrashers, catbirds, robins, blue jays, and mourning doves (*Chapman 1947b*). The dense crowns of hawthorns afford protective cover not found in other shrubs or trees. The frail nests of mourning doves are amply anchored against storms. The thorny branches serve as a deterrent to nest predators such as mammals and possibly snakes.

In addition to providing food and cover for wildlife, hawthorns impart aesthetic appeal in the landscape. This large genus of shrubs presents a variety of crown forms, ranging from columnar, flat-topped to roundish outlines

(*Hoover 1961, Watts 1946*). Hawthorns have been used in landscaping estates, campuses, and other open areas. They contribute to landscape displays through the seasons by their white bloom in spring, their summer foliage, their crimson fruit in autumn, and the gray outlines of their crowns in winter.

Hawthorns are used for screening and for hedges. They have proved valuable in public camping areas for screening between campsites. An outstanding demonstration of this is the Forest Service's Buckaloons Recreation Area in Warren County, Pennsylvania. Hawthorn hedges serve as barriers because their thorns render them formidable. The same trait applies when used for screenings.

PROPAGATION

For those interested in improving wildlife habitat, the best solution to the problem of propagating hawthorns would be the establishment of nurseries consisting of native species. Such nurseries would provide an available source of the most valuable early-, medium- and late-ripening species. The seed source must be certified as to species; otherwise the fruiting potential and adaptability of the stock may be low.

Commercial nursery stock is expensive, and hawthorn species offered for sale are usually either of exotic or unknown origin. Growing native hawthorns for commercial distribution no doubt entails financial risk on the part of the operator. Will the demand for hawthorns in wildlife plantings be of sufficient volume to warrant the establishment of hawthorn nurseries? Assuming that a nursery is a feasible economic undertaking, one must consider these factors for successful operation. First, a seed source of preferred native species must be located. Second, pretreatment of seeds before planting needs careful consideration. And third, the nursery must be protected against browsing by cottontails.

The fruiting potentialities and other qualities of native hawthorn in Pennsylvania and western New York have been under study during the past 16 years. Because of their annual yield ratings and site adaptability, those species named in table 1 are recommended for propagation in wildlife habitats. Other hawthorns that occur in the aforementioned states, but are not recommended, include 25 species or varieties in 11 series.

Table 1.—Hawthorns recommended for wildlife habitat

Common name	Scientific name[1]	Height, feet	Fruit availability
	CORDATAE SERIES		
Washington hawthorn	*C. phaenopyrum* (L. f.) Medic	33-39	Fall-winter
	CRUS-GALLI SERIES		
Cockspur hawthorn	*C. crus-galli* L.	to 33	Fall-winter
	TENUIFOLIAE SERIES		
Large-seeded hawthorn	*C. macrosperma* Ashe	23-26	Fall-winter
Roan's hawthorn	*C. m. V. roanensis* (Ashe) Palmer	23-26	Aug.-Sept.
	SILVICOLAE SERIES (THE MIDTHORNS)		
	C. beata Sarg.	20-23	Fall-spring
	C. brumalis Ashe	20-26	do
	C. levis Sarg.	10-13	do
	C. populnea Ashe	20-23	do
	PRUINOSAE SERIES (THE PRUINOSE THORNS)		
	C. compacta Sarg.	10-13	Fall-winter
	C. gattingeri Ashe.	20-23	do
	C. porteri Britt	10-13	do
Frosted hawthorn	*C. pruinosa* (Wendl.) K. Koch.	23-26	do
	COCCINEAE (THE LARGE-LEAVED THORNS)		
	C. anomala Sarg.	20-23	Aug.-Oct.
Ontario hawthorn	*C. pedicellata* Sarg.	20-23	do
Pennsylvania hawthorn	*C. pennsylvanica* Ashe	29-33	do

[1]According to Ernest J. Palmer in *Fernald 1950: 767-801*; and *Gleason 1963b, v. 2: 338-374.*

The Washington hawthorn excels others for its consistent year-to-year fruiting. First, this hawthorn flowers after the first of June in central Pennsylvania when chances of frosts are nil. Second, its towering, columnar habit of growth enables it to compete better than other hawthorns with other woody vegetation. In hawthorn propagation projects, the Washington thorn should represent about a third of the planting stock.

Seed of native hawthorns is the most economical and dependable source of propagating material in wildlife habitats. However, the seeds usually exhibit double dormancy and may need special treatment to stimulate germination during the first spring after ripening. Scarification in sulfuric acid and two-stage stratification (warm-cold) have been recommended (*Flemion 1938*).

It is a standard nursery procedure to collect fruits in the fall and macerate them to remove seeds from the pulp. Cleaned seeds are dried to remove surplus moisture that would cause heating in storage under warm fall temperatures. Refrigerator storage of seeds is a common method of holding seeds, but this practice should be used only as a stop-gap measure before drying or stratification. Seeds should be mixed with sand, the mixture of sand and seeds placed in small wooden boxes lined with ⅛-inch hardware cloth, and the boxes stored outdoors for spring planting. But I have had good results by collecting the fruits, storing them outside over winter enclosed in hardware cloth trays (to protect them from rodents, etc.), and planting them into rows in prepared soil in the spring.

Direct-seeding in wildlife habitats and grafting are other methods in hawthorn propagation. Poor results or long waiting periods are likely to result from direct-seeding. Grafting among the species of hawthorns has been successful, but there are drawbacks in matching height-growth forms. The Washington thorn attains a small-tree habit of growth. When this thorn is grafted to one of the low-growing shrubby species, the resulting grafted scion is stunted. The dotted or "gray" hawthorn (*Crataegus punctata* Jacq.) also has a small-tree habit of growth. Since it is the most common and widely distributed hawthorn in the region, grafting of the Washington thorn to this species is recommended.

Because of the hawthorn rust, propagation of hawthorns should not be attempted in areas where redcedar is abundant. The cockspur thorn is the only common species resistant to leaf rust, but even this species suffers rust damage to its fruits.

MANAGEMENT

This discussion will deal with maintenance of existing hawthorn stands, renovation of invaded stands, establishment of new ones, and the control of disease. Since other native shrubs of value to wildlife are usually associated with the hawthorns in the same sites, preservation and management of these other shrubs must also be considered.

Management of existing stands is a maintenance operation. Since hawthorns and many other shrubs thrive only during a temporary stage in succession, removal of tree invaders is necessary to retard encroachment. Removal consists of cutting invading tree seedlings, saplings, and trees where necessary. In some areas, the sweet crab apples will also need to be thinned to prevent them from crowding the hawthorns.

There are also former hawthorn stands that have been overtopped by sapling and pole-sized trees. Renovating these sites involves cutting the overstory trees. The operation is nearly always worth the effort because there is usually enough suppressed hawthorn regeneration to resurge; furthermore, these sites usually contain a good seed source in the soil.

Establishing new stands either from seed or nursery stock is a long-term project. Before wildlife values are realized, there will be a waiting period of several years, depending on the wildlife species. The project must have a clear objective as well as continuing interest to follow it through. If tree seedlings are also present, they may take over the site while the hawthorns are developing.

Cedar rust can be controlled by cutting the redcedars in areas where they are scarce. But in the Piedmont and Coastal areas, where redcedar is abundant, the job of control is futile. In these areas, the only solution is to go to a rust-resistant species of hawthorn.