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REFRACTORIES

REFRACTORIES

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Preface

The Refractories Institute is a national trade association representing a large number of refractory manufacturers and suppliers of raw materials in the refractory industry in the United States, Canada and Mexico. Each year, the Institute receives many inquiries for general information on the scope and nature of the industry, for data in the refractory-user industries and for illustrations of how refractories are installed or used. This Refractories booklet is published for the non-technical reader who wants to know more about refractory products and applications. This booklet describes the various types of refractories and their uses. The accompanying drawings are generalized to portray the broadest applications.

Additional copies of this booklet are available from The Refractories Institute. Prices will be quoted upon request.

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REFRACTORIES
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I. SIGNIFICANCE

what are refractories?

Refractories are heat-resistant materials that provide the linings for high-temperature furnaces and reactors and other processing units. In addition to being resistant to thermal stress and other physical phenomena induced by heat, refractories are usually required to withstand physical wear and corrosion by chemical agents. Refractories are often exposed to environments above 1000°F (538°C).

While this definition correctly identifies the fundamental characteristics of refractories – their ability to provide containment of substances at high temperature for useful purposes – one should realize that refractories comprise a broad class of materials having the above characteristics in varying degrees, for varying periods of time, under varying conditions of use. There are a myriad of refractories compositions in a vast variety of shapes and forms which have been adapted to a broad range of applications. The common denominator is that in usage they will be subjected to temperatures above 1000°F (538°C) at times, or at all times when in service. [redacted] Refractory linings are made from brick and fired shapes, from specialties (such as plastics, castables, gunning mixes or ramming mixes), or from combinations of brick and specialties.

Most refractory products, in final shape, are something like a typical construction brick. But there are a vast number of shapes and forms because it's not possible to press out all shapes in a mold. The size of the shapes and forms range from items as small as a little finger to as big as a solid block weighing several tons.

what are refractories made of?

Refractories are made of natural and man-made materials, usually nonmetallic, or combinations of other compounds and minerals such as alumina, fireclays, bauxite, chromite, dolomite, magnesite, silicon carbide, zirconia, and a host of others.

what are refractories used for?

In general, refractories are used to build structures subjected to high temperatures, ranging from the simple to the sophisticated, from fireplaces to thermal insulation for spacecraft. In industry, they are used to line boilers and furnaces of all types, reactors, ladles, stills, kilns and so forth, as explained in detail in the latter parts of this booklet.

Depending upon the application, refractories must resist chemical attack, withstand molten metal and slag erosion, thermal shock, physical impact, catalytic heat and similar adverse conditions, generally while at high temperature. Since the various ingredients of refractories impart a variety of performance characteristics and other factors, many refractories have been developed for specific purposes. It is not by chance that more than 5500 brandname products are listed in the latest *Product Directory of the Refractories Industry in the United States*. This directory is available from The Refractories Institute.

II. HISTORY

historical evolution

The development of refractories has paralleled the development of ceramic and metal technology since very ancient times. We know that refractories in some form were necessary for metal processing as early as the bronze and iron ages, over 10,000 years ago.

The first recorded use of refractories in the original thirteen colonies may have been for glass pots in the glassworks at Salem, Massachusetts in 1638. English or German clays may have been imported for this purpose. Less than a century later, domestic clays were being utilized for crucibles and glass pots in Connecticut and New Jersey. By the second half of the 18th century, glassmaking was becoming more widespread and so obviously was the making of refractories to supply them. By the second half of the 19th century with the great growth of glassmaking in the Pittsburgh area, the manufacture of glass pots had become an established separate industry in Pennsylvania and Ohio.

Iron-making in America sprang up almost at the same time as glassmaking. The first commercially successful blast furnace was built at Saugus, Massachusetts in 1645, and was probably lined with a natural refractory material such as schist, a largely silica rock.

The identity of the first American firebrick manufacturer is uncertain. It is known that firebricks were imported from England in the 17th and 18th century, but by the end of the latter century, domestic furnace tile and brick were being manufactured for use in glass furnaces in New England.

There seems little question, however, that the commercial production of firebrick spread rapidly after the American Revolution. As early as 1793, fireclay was being shipped from New Jersey to Boston where it was being used for firebricks. In the early years of the 19th century, more firebrick manufacturers sprang up throughout New England, Pennsylvania, and Ohio, and as far west as Missouri, Colorado and California.

In early years, the sale of firebrick was often a supplementary product for kiln operators primarily engaged in glassmaking or ceramic manufacturing. After the Civil War with the impetus given by the rapid expansion and industrialization of the United States, refractory manufacturing became a specialized industry. During this period, many of the companies still operating today were founded and grew rapidly.

To this point, the American Industrial Revolution began in earnest following the Civil War.

One industry, and then another, expanded to provide the basic materials necessary to "build" America. Bigger steel mills and improved techniques were developed; new types of steelmaking furnaces followed the other, each producing more tons of steel per hour; steam engines and steam ships demanded more and more refractories; new metals were discovered, and improved foundry techniques created increased market demands for refractory products.

After World War I, the sophistication of both the refractory and the end-user industries grew. The aluminum industry began to expand to meet new business needs, as did the glass and hot metals industries. Growth of the refractory industry was now a combination of supplying a wide variety of products to fit specific industrial needs. This included the end user industries, which were developing new items and demanding new and higher-performing refractories.

Small companies now began to merge to take advantage of joint research capabilities. And as basic industries changed, many companies just could not keep up with new and different product lines. Thus, the domestic refractory industry made a leap into the future following World War II, and its ability to adapt to change was now to be the strength of its survival.

Some of the important developments in the last phase have been:

Silica Refractories First made in South Wales in 1842, they were produced in the U.S. by the mid-1860's. The first separate American silica brick plant was opened in 1899 at Mt. Union, PA and others followed soon nearby and later in Chicago.

Chrome Refractories As bricks, they have been in use since 1896.

Magnesite Refractories Initially used in Europe, this material was imported from Austria and was first used successfully in 1888 at Homestead, Pennsylvania. Commercial production of magnesite from seawater developed in the 1940's, with the first commercial production in the U.S. in California. Further developments in improved bonding systems for magnesite shapes have continued.

Dolomite Refractories Also initially used in Europe, fired and organically bonded dolomite bricks have been produced in the United States since 1965.

High-Alumina Refractories Domestic bauxite was discovered in Georgia in 1888 and in Arkansas three years later. Missouri diaspore was recognized for its unique qualities for superduty applications in 1917. In recent years, techniques for the utilization of Southern kaolin clays have been developed. All these materials are excellent sources of aluminum oxide which imparts improved performance to these refractories.

Insulating Refractories Insulating firebrick were developed in the mid-1920's, and recently improved for use in higher temperature environments.

Plastics and Castables These unformed refractories have been increasingly popular for forming monolithic structures. They are applied by various methods including troweling, tamping and gunning (a development of the 1920's). The use of plastics, castables and other monolithic refractories was greatly accelerated during World War II because of the shortage of brick and fired shapes. "Low moisture" castables are low cement materials that require less mixing water than normal castables.

Fusion-Cast Refractories Alumina-silica and zirconia are used for the casting of molten refractory materials in blocks. These products were developed over the last 50 years.

Ceramic Fiber

Ceramic fiber was first developed for commercial use in 1942. Composed primarily of alumina-silica, ceramic fiber has found widespread acceptance in many types of industrial furnaces, ceramic kilns and chemical process heaters. Ceramic fiber furnace linings provide low thermal conductivity and low heat storage resulting in reduced energy usage and shortened firing cycles when compared to conventional refractories. Product forms available include blanket, modules, board, paper and sprayable bulk fibers. Installation techniques include layered blanket, edge-stacked or folded blanket in module form, board-over-blanket systems and, most recently, spray applied methods. Ceramic fiber may be utilized as a full-thickness furnace lining or applied over existing refractories to upgrade furnace efficiency. Its lightweight, resiliency and immunity to thermal shock also offer advantages in furnace lining applications. With the advent of polycrystalline mullite ceramic fibers, systems can be designed for operating temperatures up to 3000°F (1650°C).

Refractory Fiber

The first patent for a steam-blown alumina silica fiber was filed about 1940. Simultaneous development work was underway on the ability to fiberize with other methods. In the late 1940's, joint development took place between fiberization technology and electric-melt technology. The result was the introduction of refractory fiber felt for the aerospace industry. The 1950's saw the commercialization of various forms of refractory fiber for application and general industry uses.

By the 1980's, the refractory fiber production had expanded to worldwide manufacturing locations. End use applications have become very diverse; they range from the exotic applications associated with the aerospace industry and the applications of the metal form industries to the traditional appliance and automotive markets.

III. CLASSIFICATIONS

[redacted]

The primary types of clay refractories are fireclay, high alumina, insulating and ladle. [redacted] Some of the properties of each are discussed in this section.

CLAY REFRACTORIES Standard Industrial Classifi-[redacted]

Fireclay

Fireclay is an earthy or stony mineral aggregate which has as its essential component hydrous silicates of aluminum, with or without free silica; plastic or formable when sufficiently pulverized and wetted; rigid when subsequently dried; and of suitable refractoriness for use in commercial refractory products.

Fireclay deposits are seldom pure hydrous aluminum silicates; the nature and percentage of impurities found in the fireclay help determine the properties of refractories made from them. Fireclays from various deposits are mixed in varying amounts to produce products with differing refractoriness. Fireclay refractories are classified as *low-duty, medium-duty, high-duty, or super duty* depending on their resistance to high temperature or refractoriness.

Fireclay brick have moderately high resistance to high temperatures, low thermal expansion, and provide reasonable thermal insulation. They have some resistance to attack by acidic materials but fail rapidly when exposed to chemically basic materials at high temperatures.

High-Alumina

High-alumina refractories were originally based on diaspore but are now made of bauxite or other raw materials containing from 50% to 87½% aluminum oxide. Compositions containing from 50% to 87½% aluminum oxide are classified for statistical purposes by the Bureau of Census as *clay* refractories; those with over 87½% percent are classified as non-clay, extra-high alumina refractories.

In its naturally occurring form, bauxite contains a number of impurities, primarily silica, titania and iron oxides. The properties of high-alumina compositions change with increasing percentages of aluminum oxide. Compositions are available from 50% to 87½% aluminum oxide. These are multipurpose refractories, some suitable for temperatures up to 3200°F (1760°C) and highly resistant to chemical and slag attack. Depending on composition and impurities, they have fair-to-excellent resistance to chipping and somewhat higher volume stability than most other clay refractories.

Insulating

Insulating refractories can be made of high alumina or fireclay materials. They are made by two general processes. In one, a combustible material added to the composition mix burns out during manufacture leaving porous spaces which result in low density, making it a better insulator. In the other, a lightweight ingredient such as expanded clay or perlite is added to the composition to lower the density of the finished product.

Insulating firebrick are in a range of compositions available commercially with temperature tolerances to 3300°F (1815°C).

Depending on their use, insulating refractories may be the primary refractory, or may be a backup layer for a denser, more heat-resistant refractory. This scheme conserves energy and protects the shell of the container from the high temperature inside the refractory lining while the denser refractory resists high temperatures up to 5000°F (2760°C), slags, acidity, and the like.

Ladle

Ladle brick are considered a unique fireclay refractory. They are of two general types: a *bloating brick* made from fireclay of moderate refractoriness but which expands (or bloats) significantly when heated at 2336°F (1280°C) or above; and a *volume stable brick* made from fireclay with good refractoriness which shows little or no volume change when heated to 2336°F (1280°C) or above. High density and low porosity are important in both types.

Current ladle metallurgy processes include the use of high-alumina, dolomite, magnesite-chrome, magnesite-carbon, dolomite-carbon, and dolomite-magnesite brick and castables, plastics and ramming mixes.

NONCLAY REFRACTORIES Standard Industrial Classification [redacted]

Basic

Basic refractories are produced from a composition of dead-burned magnesite,dolomite, chrome ore, or compatible mixtures of magnesite-dolomite, magnesite-carbon, dolomite-carbon or magnesite chrome. Early magnesite brick were produced from natural minerals that contained a number of impurities that limited their refractoriness. Magnesium oxide (MgO), the primary metallic oxide in magnesite, is highly refractory in its pure form: its mineral name is periclase. Impurities in both natural magnesite and chrome ores lead to the formation of low-melting compositions which greatly diminish refractoriness.

However, as a class, the magnesia-chrome combinations have good mechanical strength and volume stability at high temperatures. In addition, they have resistance to corrosion by chemically basic slags, especially those found in the steel and copper industries.

Chrome-magnesite combinations—a larger proportion of chrome than magnesite—exhibit less thermal expansion than high magnesia compositions.

Chrome-free compositions of high purity sea-water or brine-well magnesia or high purity natural magnesite, often referred to as periclase, provide maximum refractoriness and resistance to iron oxides. With coal tar binders, these compositions are particularly suited for steel furnaces using the basic oxygen process (BOP). Tar bonded dolomite and magnesite-dolomite compositions are also well suited for lining sections of BOP vessels.

For the most severe areas of BOP vessels and electric arc furnaces, magnesia-carbon bricks are used. This group of products have carbon contents typically ranging from 5 to 35%. The carbon is provided by additions of natural flake graphite. Magnesia-carbon brick have outstanding resistance to corrosion by steel making slags.

Extra-High Alumina

Extra-high alumina refractories are made predominately from bauxite or alumina (Al_2O_3) which has been fused or densely sintered. Extra-high alumina refractories contain from 87½% to slightly less than 100% alumina. Most extra-high alumina refractories have good volume stability at temperatures up to 3300°F (1815°C).

Fused Cast

Some of the materials mentioned as nonclay refractories are formed into special shapes by fusing in electric furnaces and pouring, while still molten, into molds. Fused casting is applied to magnesite-chrome, alumina, and compositions of alumina-zirconia-silica. Their chief characteristics are resistance to glass and slag corrosion, abrasion resistance, and high refractoriness with volume stability under extended high-temperature conditions.

Mullite

Mullite ($3Al_2O_3\ 2SiO_2$) refractories are made of kyanite, sillimanite, andalusite, bauxite, or mixtures of aluminum silicate materials to give about 70% alumina. Any of these materials must be sintered at high temperatures or melted in electric furnaces to bring about the formation of mineral mullite. This is the most stable of any alumina-silica combination. These refractories are noted for their low level of impurities and their excellent resistance to load at high temperatures.

Silica

Silica is a naturally occurring element found abundantly in the earth's crust. Fine-grained deposits with low deposits of alumina and alkali make excellent refractories with high temperature load bearing ability. Principal uses for silica refractories today are in coke ovens, glass melting furnace crowns and, in Europe, as checker brick in blast furnace stoves.

Silicon Carbide

Silicon carbide (SiC) is produced by reaction of sand and coke in an electric furnace. It is used to make special shapes, such as kiln furniture, which are used to support and separate pieces of ceramic ware as they are fired in kilns. Silicon carbide has exceptionally high thermal conductivity (it transmits heat readily), has good load bearing characteristics at high temperatures, and good resistance to rapid changes in temperature.

Zircon

Zircon is a naturally occurring zirconium silicate ($ZrO_2\ SiO_2$) mineral. It has good volume stability for extended periods of exposure to high temperature. Zircon is frequently used for nozzles to control the flow of molten metals. Zircon refractories are widely used for glass tank construction where resistance to certain molten glasses is required.

Other Non-Clay

This group includes alumina-zirconia-silica, chrome-alumina, forsterite, graphite, magnesia-alumina, pyrophyllite-andalusite, and zirconia—each having special properties for specific industrial uses.

IV. MANUFACTURING PROCESSES

T[redacted].

Th[redacted]t is shown on Page 43.

V. FORMS

Refractories are produced in two basic forms: [redacted] in granulated or plastic forms. T[redacted] The unformed products, depending on composition and application, are categorized as *specialties or monolithics* and identified as plastics, ramming mixes, dry vibratables, castables, gunning mixes and mortars. Specialties are installed by ramming, casting, troweling or gunning.

Brick and Shapes

Brick and shapes are the backbone of the refractory industry. They evolved from the standard rectangular brick form to a wide variety of special shapes designed to fit specific furnace structures. Compositions are designed for particular service conditions. The standard brick measures 9 inches long, 4½ inches wide, and 2½ inches thick, with a volume of 101.25 cu. in. Production and shipment of brick and shapes refer to this standard and are reported in terms of 9 inch equivalents.

The standard rectangular brick is a useful form to build straight walls. Other forms are required for the arch of a furnace or other curved designs. Standard tapered brick, called arches, keys, and wedges, are furnished for these needs.

Special shapes have been designed to assist in the construction of total enclosures with curved interior faces to avoid sharp, angular corners. Other special shapes are: *skew block*, used at the outside edges of arches; *floor tile, muffle wall tile,* and *grid section tile* for heat exchangers; and blocks of various shapes and sizes with openings in the block for the insertion of burners in furnaces. There are special shapes used to control the flow of molten metal or glass once it has left the furnace; these are identified as *runners, gates, sleeves, nozzles,* or *troughs*.

Close cooperation exists between refractory producers and end users in adapting refractory shapes for specific applications.

Crucibles

Crucibles are the oldest refractory form known. A crucible is a ceramic pot or receptacle used in melting metals, made from refractory materials with a relatively high thermal conductivity. Crucibles are still widely used today in non-ferrous foundries. The crucibles are used in either fuel fired or induction furnaces. Selection of the proper crucible is based on composition, shape, and size. The metal chemistry dictates the crucible composition chosen. Typical metals processed in crucible melting furnaces include aluminum, zinc, brass, copper, and steel.

The three major crucible composition groupings are:

Carbon-Bonded Crucibles – Composed primarily of silicon carbide and graphite with other refractory materials present and having a bond of residual carbon resulting from the distillation of organic materials such as tars or resins. The crucible is protected against oxidation by the use of glazes.

Clay Graphite Crucibles – Contain high percentages of graphite with some silicon carbide having a ceramic bond composed of clay and other refractory constituents. The specific melting and/or holding requirements of fuel fired and induction furnaces dictate the composition.

Oxide Refractory Crucibles – Alumina, silica, magnesia, zircon, and mullite compositions which are ceramically bonded make up this group of crucibles. They are primarily used for induction ferrous melting.

Metal melting with a crucible offers a variety of advantages: 1) Individual crucible selection prevents metal contamination. 2) Fuel costs are reduced due to more efficient heat transfer. 3) Faster melting due to heat transfer. 4) Crucibles are designed for longer service life resulting in lower maintenance cost.

Specialties–Mortars, Moldables, Castables

[redacted]

[redacted]. The goal is to achieve a lining that comes as close as possible to being a monolithic and continuous refractory structure.

As the name implies, [redacted]. After drying, either the heat from firing the equipment or a chemical binder converts the plastic material to a solid, monolithic structure. Plastic refractories are available in both clay and nonclay compositions.

[redacted] Castables are particularly suited to the molding of special shapes and parts at the installation site. They can be used for forming complete furnace linings, and other unique shapes. They can be applied by pouring, pumping, troweling, and gunning. They have the advantage of being readily usable at the operating temperature of the the equipment after hydraulic or chemical setting and removal of all moisture has taken place.

[redacted] The principal requirements are that they can be blown into position by air pressure through a lance or nozzle, and are sticky enough to stay where they adhere on impact and build up to the desired lining thickness.

They are used for patch-type repairs, especially inside empty but still hot furnaces. For example, to patch a basic oxygen furnace, a lance (gun) projects through a heat shield behind which an operator directs the placement of the refractory onto the hot lining.

Gunning mixes are also suitable for placing refractory linings in confined spaces, such as petroleum reactors and pipes, or large exposed areas such as the walls of soaking pits, as well as many other types of linings. Their compositions may be based on clay or nonclay materials, which become a monolithic refractory upon hardening in place.

[redacted]

Refractory users are finding it more advantageous to buy "preformed" shapes than to have those shapes made on site. Some of these advantages include: 1) [redacted] The preformed shapes can literally be lifted from a truck and placed in position. 2) [redacted] (Larger shapes can be utilized, minimizing the number of shapes required.) 3) [redacted] 4) [redacted] 5) [redacted]

Preformed refractory specialty shapes can be used in nearly every area where refractory products are installed such as electric arc, blast and basic oxygen furnaces, to name a few.

VI. APPLICATIONS

Refractories are used wherever the control or containment of high temperature processes is required. Applications range from the nearly indestructible home fireplace lining to the single use, self-sacrificing nose cone on re-entry vehicles. However, most refractories are used by industry in connection with a wide range of processes, including the conversion of energy from one form to another.

Refractories are necessary, in most cases, whenever high temperatures are involved.

The following sections contain general descriptions of some industrial applications of refractories. Their selection illustrates a broad range of commodities produced, but is by no means all inclusive. Neither is it intended to show all of the refractory-using processes in the production of any single commodity, such as steel. Hopefully, it will clarify the importance of refractories in such areas as furnaces.

A furnace is an enclosure designed to operate at high temperatrures. The useful purpose of the furnace may be: space heating; production of electricity; the melting, shaping, and refining of metals or glasses; or initiation and completion of chemical reactions. Furnaces come in many sizes and shapes.

Aluminum Melting Furnaces

The production of aluminum alloys from new metal or the refining of scrap aluminum requires that solid materials be heated until they melt. Pure aluminum melts at 1220°F (660°C), but the molten metal temperature usually exceeds 1292°F (700°C).

The *aluminum melting furnace* shown on Page 23, is known as a reverberatory furnace. In this type furnace, the fuel is directed over the metal to be heated. The furnace is heated by the two burners located high in one of the endwalls. It is charged (loaded) with solid materials through the doors on one side wall, and discharged (unloaded) through a tap hole located just above the furnace floor. Temperatures in the upper part of the furnace, above the molten metal range from 2012° to2372°F (1100° to 1300°C).

The floor of the furnace is built up of multiple layers of refractory. The multiple layers support up to 150 tons of metal the furnace may contain at one time, and protect against a break-out that would pour this metal on the factory floor. Up to the highest level of molten metal, high alumina, silicon carbide, mullite, and zircon refractories are used to prevent metal penetration or slag attack. Above the metal line, super-duty firebrick, plastic or castable are used. The flue is lined with high duty firebrick and the charging doors are filled with a castable.

An aluminum melting furnace occasionally may require minor patching near the charging door, due to mechanical abrasion from the solids being loaded. This could come any time after a month or so of use, but major rebuilding should not be necessary until after a year or more of use. There are also quantities of refractories used in carbon anode baking furnaces in the aluminum industry:
high duty, super duty, and high alumina brick and a variety of clay/alumina specialties.

Boilers

Boilers are furnaces designed primarily to produce steam. The steam may be piped throughout a building for space heating, used by a factory in a manufacturing process, or run through a turbine to produce electricity. Industrial boilers can be up to 100 feet high. They usually burn coal, oil, or natural gas, but are also designed to burn waste products, such as the liquid residue of the wood-pulping process.

The power plant boiler illustrated on Page 24, has an overall height of 60 feet. The end walls of this furnace are built up of 3 layers of firebrick; the inner layer is super-duty firebrick and the outer 2 are insulating brick. Specialty refractories (plastics and castables) are also used. The water tubes that line the side and top of this furnace absorb much of the heat generated by the burners. As a result, the side wall can be of a lighter refractory construction. The inner lining may be a layer of insulating firebrick with block insulation outside. Combustion chamber temperature seldom exceeds 2800°F (1540°C).

Coal-burning boilers fed by stokers usually have the combustion chamber and ash pit lined with dense, super-duty firebrick to resist the abrasive action of the ash. However, if the boiler is fired with pulverized coal blown into the furnace, the ash pit will probably have a monolithic refractory lining, usually applied by gunning or troweling.

Recovery furnaces, such as those used in the kraft paper industry, need a dense basic chrome refractory as the combustion chamber lining in order to resist the corrosive effect of the chemicals in the spent liquid residue. The molten ash resulting from this burning process is collected in the bottom of the furnace and is chemically very corrosive.

Power plant boilers and industrial boilers for the manufacture of steam may last 10 to 15 years before rebuilding, but recovery furnaces have to be rebuilt about every third year because of the corrosive nature of the residue being burned and its molten ash.

Incinerator boilers utilize municipal waste for fuel and require considerably greater amounts of refractory to protect metal parts from corrosion and wear. The studded boiler tube walls utilize high silicon carbide gunning refractories. Along the grate, high alumina or silicon carbide brick shapes are used to resist the abrasion of the trash. In the ash hoppers alumina monolithics are usually installed by gunning or casting.

Coke Ovens

Coke is the residue remaining from the carbonization of certain types of coal in enclosed areas. The manufacture of coke in the United States began approximately a century ago. For almost 50 years, coke was made in beehive ovens constructed of silica brick along with various grades of fireclay where conditions permitted. The modern "coke oven" is actually a "chemical recovery" or "by-product" oven which heats the coal through the oven walls, and in the absence of air.

A by-product coke oven battery consists of a row of individual ovens placed side by side. The ovens are separated by refractory walls which enclose the heating chambers from which heat is supplied. Holes for charging coal and for exhausting volatile products are located in the oven roof. The ends of the oven are formed by removable doors which permit the finished coke to be pushed from the oven. The ovens are regeneratively fired with gas fuel, the heating chambers in each oven wall being connected by flues to separate regenerator chambers beneath the oven and wall structure. The regenerator chambers are connected by flues to the air supply and to an exhaust stack.

Ovens, chambers, and critical wall sections are constructed with silica shapes of which literally thousands of different sizes are required in each installation. High, medium, and low duty fireclay brick, shapes and monolithics are selected for various other sections of walls, flues and doors as conditions require.

Insulating refractories of all types–brick plastics, castables, and gunning mixes–are extensively applied to assure maximum conservation and utilization of the required process fuel. Refractory bonding mortars are selected that are compatible with the various types and classes of brick used in the construction of the coke ovens. All joints must be tightly sealed to be as impenetrable as possible to gas leakage.

Blast Furnaces

The blast furnace is a highly specialized furnace designed to chemically reduce iron ore to metallic iron continuously for extended periods of time. In addition to resisting alkalies, carbon monoxide gas, and temperatures that exceed 3200°F (1760°C), the lining of the furnace must be highly resistant to thermal shock and the abrasive action of a charge consisting of iron ore, coke, and limestone. These are loaded into the top of the furnace and gradually work their way down as the ore is chemically reduced to molten metal. The coke is consumed when generating the atmosphere necessary for chemical reduction.

As shown on Pages 12 and 13, the base or hearth of a blast furnace consists of mutiple layers of firebrick, super-duty firebrick, or carbon blocks with carbon brick or super-duty firebrick in the side walls up to the level of molten iron and slag. Because of the corrosive/erosive conditions in ironmaking, cooling has become as important as refractory selection at and above the tuyeres. Page 12 illustrates copper cooler plates which extend into the refractory wall to help conduct heat outward to the furnace shell; cast iron staves at the shell (not shown) are an alternate cooling technique.

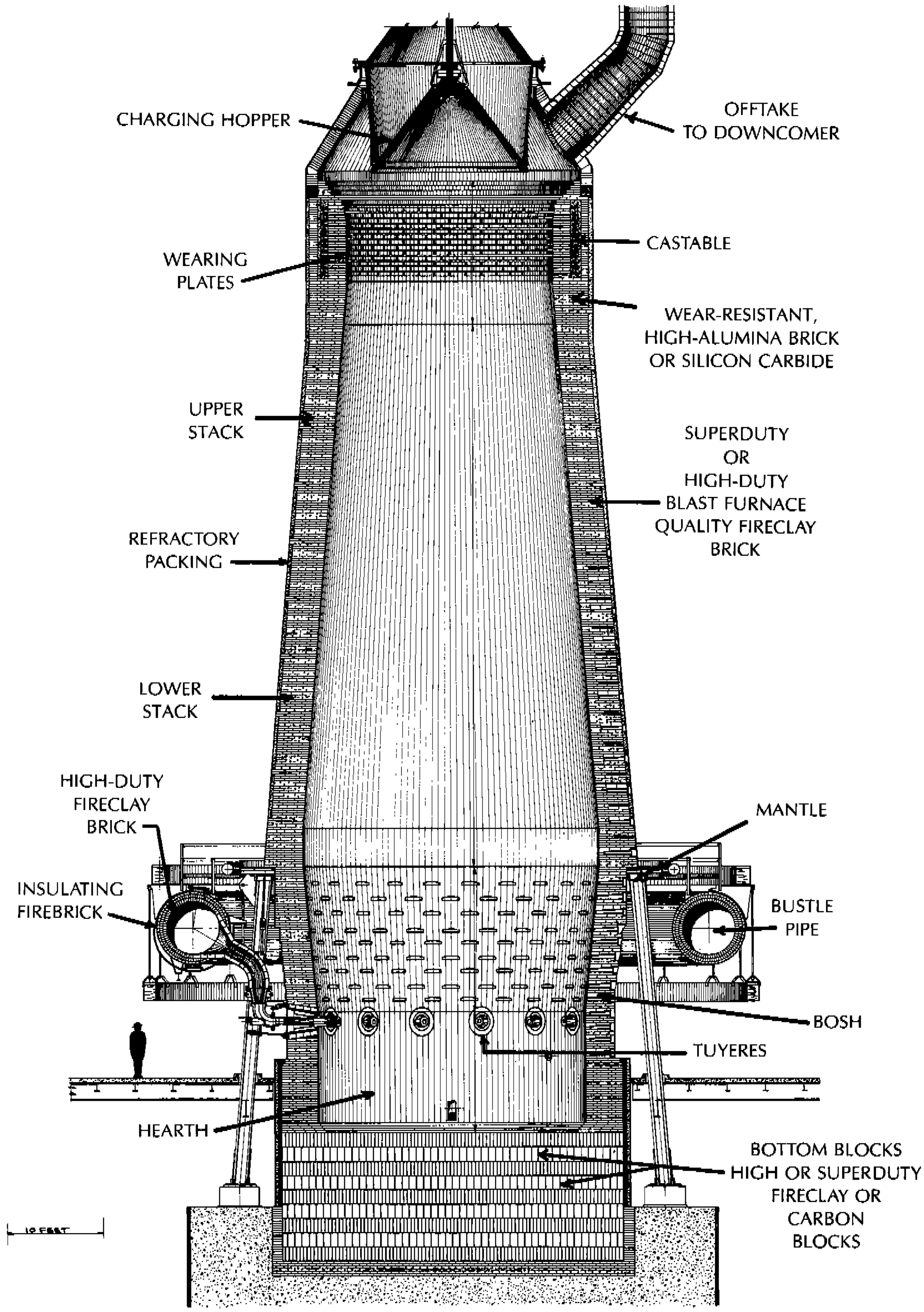
In most post World War II furnaces, intermediate conductivity silicon carbide brick have been used to protect cooler plates and/or to face staves from tuyere band to mid stack. Super duty firebrick is used at the inside hot face and for the upper stack lining.

Just under the charging hopper at the top of the furnace, the interior is lined with a refractory having high impact and abrasion resistance, such as wear resistant alumina brick or silicon carbide, in order to absorb the shock of the periodic loading of raw materials to the furnace. The "bustle" pipe that surrounds the base of the furnace is lined with high-duty firebrick and insulating brick as a back up. Refractories in the bustle pipe are required because of the hot air blown into the furnace by way of the pipe and the tuyeres (the openings by which the pre-heated air enters the furnace) has been pre-heated in external stoves in order to speed up the reaction that takes place in the furnace and to reduce coke requirements.

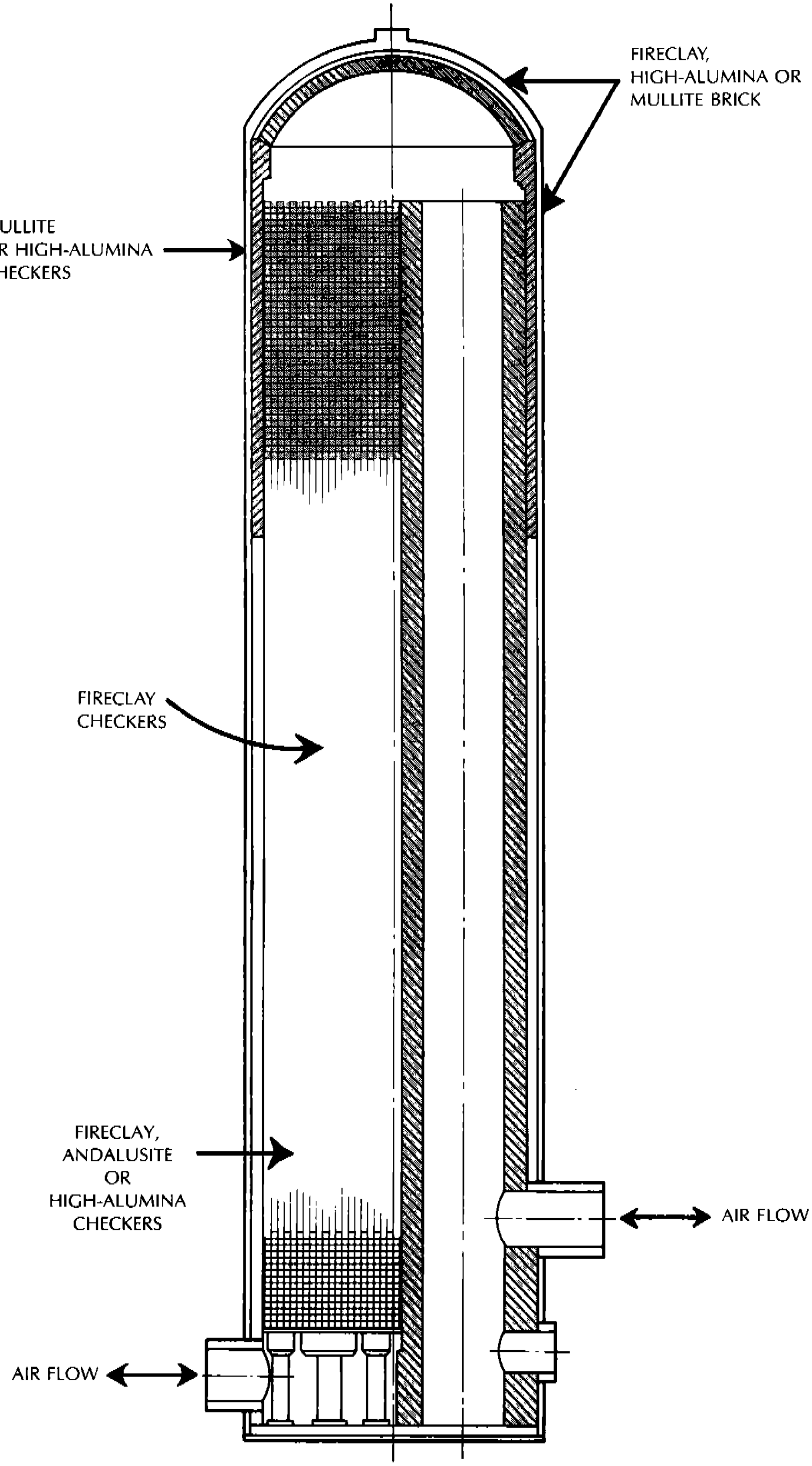
Further, the offtake at the top of the furnace where the combustion products exit is also lined with firebrick since it may have a temperature approaching 1004°F (540°C). The external stoves contain refractory brick stacked in a checkerboard pattern called checkerwork. Most blast furnaces have three stoves, which alternately pre-heat the air going into the furnace to a temperature of 1500° to 1994°F(815° to 1090°C) or more. The checkerwork and linings in the stoves are semi-silica, high-duty, super-duty, high alumina, or mullite brick or shapes. Within the last ten years, a need for higher blast temperatures has created a demand for the new thin-walled, multi-hole, interlocking, high-efficiency checkers for new and/or upgraded stoves. The same materials are used in some areas of the linings and checkwork but with tighter specifications on creep resistance. In the most critical areas, checkers containing andalusite are generally utilized.

Current blast furnace design in the United States includes hearth diameters up to 45 feet, with the overall height of the larger models approaching 200 feet above ground level. Under normal circumstances, the principal point of wear in the blast furnace lining is at the bosh and lower stack areas and results from action of slag, volatile alkalies, and other volatile fluxes.

Normal life, before replacement of a blast furnace, may be as short as 3 years or as long as 10 years. The average life span lies somewhere between 6



TYPICAL MODERN BLAST FURNACE FOR REDUCING IRON ORE TO IRON METAL



A TWO PASS BLAST FURNACE STOVE

and 7 years. During this life (called a *campaign* by the industry), the daily production of iron will range from 1000 tons for the small furnaces to 7000 or 8000 tons for the largest U.S. installations. Applications of the blast furnace include:

Cast House Floor

There are basic areas of refractory application on the blast furnace cast house floor: the taphole and the taphole socket, the main trough, skimmer, well and iron dam, the iron runner system and the slag runner system. Each requires specialized refractory products to achieve a balanced lining life.

Taphole

The blast furnace taphole is probably the most critical refractory application area in the entire steel mill when considering safety. During blast furnace discharge, the taphole must resist iron and slag attack and must maintain a uniform taphole diameter for the entire cast.

Taphole Socket (Nozzle Socket)

Most furnaces have a mud gun nozzle socket at the furnace wall. It is important that a high quality refractory material be used to form the socket and that the socket holds its size and shape during consecutive casts.

Trough

The blast furnace trough is the receiving container for the iron and slag as it is discharged from the furnace through the taphole. Some are as short as 15 feet while others are as long as 60 feet. Most average 20 to 35 feet long. With the exception of only a few blast furnace shops, the troughs are fixed and are a permanent part of the blast house floor.

Skimmer

The skimmer forms a physical barrier which restricts the flow of iron and slag in the trough. A channel in the bottom of the skimmer allows the iron to flow under the skimmer and into the well area.

Iron Well and Dam

The iron dam prevents the molten iron from immediately flowing down the runner system to the hot metal cars. By preventing this flow, the volume of iron in the trough and well increases as the furnace continues to discharge. When the level of iron in the trough and well reaches the top edge of the dam, the iron overflows the dam and travels by gravity into the iron runner system.

Iron Runners

The iron runner system directs the molten iron from the dam across the cast house floor to either a series of gates and spouts to the hot metal cars or into a tilting spout to the hot metal cars.

Slag Runners

The slag runner system directs the molten slag from the trough across the cast house floor to the slag pots or slag pits.

Ladles

In metallurgical operations, molten metal is tapped from the furnace into ladles. Molten iron is transferred in hot metal cars as much as several miles from the blast furnace to steel making furnaces within the same plant. Molten aluminum alloys are transported from a reduction plant to a foundry sometimes several hundred miles distant.

Hot metal cars are refractory-lined tanks, usually on railroad wheels, used to transfer hot metal by the interplant railway that is common in steel mills. Their carrying capacity varies from 50 to 250 tons. (Service temperatures in the car range from 2800° to 2900°F [1540° to 1600°C]. The refractory is usually high-duty, super-duty, high-alumina, or mullite brick. They may be backed up by a layer of insulating brick on top of a refractory packing next to the steel shell. Hot metal cars will carry from 50,000 to 200,000 tons of iron before they require relining.)

Ladles are simply open pots fitted with hooks and moved up by using a crane. They are equipped with spouts or nozzles for pouring the metal at a controlled rate. Page 25 shows a conventional stopper rod bottom pour ladle, slide gate equipped bottom pour ladle and a teapot ladle. The standard top-pour ladle is similar to the bottom pour ladle without the stopper rod or sliding gate and with a pouring lip. Ladles are made in sizes ranging from a few pounds capacity to as large as 400 tons.

Especially in the larger sizes, bottom pour and slide gate ladles have a double refractory lining in order to prevent the loss of metal due to refractory failure. Ladles are subjected to considerable mechanical stress as well as drastic thermal change as they are filled and discharged. In order to meet these severe conditions, high alumina and basic ladle brick are used. These form the inner or working lining and are backed up by insulating firebrick, regular fireclay brick or high alumina brick to protect the steel shell.

High alumina ladle brick are formulated so that they expand slightly when hot metal is poured into the ladle to form a tight barrier that prevents metal penetration through the brick joints to the back-up lining or shell. Proper construction and installation techniques are much more critical to successful use of high alumina brick as compared to bloating fireclay. The latter type of brick have a much greater reheat change when in service, but significantly less resistance to melting versus high alumina brick.

Brick for steel ladles must stand molten metal and slag at temperatures up to 3100°F (1700°C), severe thermal shock, abrasion and mechanical abuse. Number of heats cast averages 60 to 100; repair of bottom and slagline may be required during the ladle campaign.

The teapot ladle, also shown on Page 25, usually has a monolithic lining. The safety lining for this type of lining is high-duty-fireclay brick or insulating fiber paper next to the shell. Monolithic linings may be either high alumina ramming mixes or castables. Refractory lining in ladles need to be particularly spall resistant and resistant to molten metals and slag to give economical service life and prevent contamination of metal by nonmetallic inclusions.

The ladle furnace is the most recent process technology in steelmaking. The ladle containing molten steel is placed under a refractory dome containing three vertical carbon electrodes. Ladle furnaces are like electric arc furnaces, however they operate at lower power consumptions. The purpose of the ladle furnace is to adjust temperature, chemistry and inclusion formation in the molten steel prior to casting. These metallurgical processes are carried out effectively and at lower cost in a ladle furnace than in a BOF or electric arc furnace.

Most ladles today are equipped with a sliding gate valve system to control the flow of metal from the ladle. The lower view on Page 25 shows this system. Refractory plates, each having a vertical orifice, are fitted together on the ladle bottom. When the orifices are lined up with one another, metal flows from the ladle. One plate is hydraulically moved to control or shut off the flow. This is a severe application for refractories, requiring high resistance to metal erosion, thermal shock and mechanical abuse. Alumina, zircon, mullite and basic refractories are used for the various parts in this system.

Basic Oxygen Furnaces

The basic oxygen furnace (BOF) is the primary steelmaking furnace in the United States today. It is a furnace for rapidly burning the carbon out of iron by blowing oxygen into the molten metal from the top. A variation of this process (the Q-BOP) blows oxygen through tuyeres located in the furnace bottom. Most recent developments combine top blowing of oxygen with bottom stirring through special tuyeres generally using nitrogen and argon. Originally used only with molten iron directly from the blast furnace, current practice uses some scrap in each charge. BOF's range in capacity from 100 to 350 tons, with the metal occupying about ⅕ of volume of the vessel. The time between charges seldom exceeds 2 hours and usually is less than 1 hour.

Page 26 illustrates the top blown BOF. The short time between charges demands a refractory that can handle high thermal stress. The thermal stresses, slag and metal turbulence during the melt create some of the most severe conditions for refractories known in the steel industry.

The construction of a basic oxygen furnace starts with installation of a safety lining of high purity burned magnesite brick, which in some cases, can be pitch impregnated on the inside of the steel shell. This is a backup lining to prevent the loss of molten metal if the primary or working lining develops a hole. The primary lining is usually zoned with various qualities of pitch or resin bonded carbon-magnesite brick containing the carbon levels of 5 to 20% or pitch impregnated magnesite brick. The linings are zoned to furnish balance wear. The carbon content promotes resistance to slag attack and thermal shock.

In the early days of BOF development, basic brick not bonded with pitch or fortified with carbon would last about 40 heats before it would have to be replaced. With today's refractories, improved operating practices and regular maintenance with magnesite or magnesite-dolomite gun mixes, it is not uncommon for linings to last 2000 heats with some campaigns lasting as long as 5000 heats.

Electric Arc Furnaces

The second most common steel-making furnace in the United States is the electric arc furnace (EAF). EAF's are used to produce steel in ingot form and for making steel castings. The electric arc furnace, illustrated on Page 27, can be constructed for acid or basic steel-making processes. However, the basic system predominates. The furnace lining in the acid system consists of high purity silica brick in the bottom, sidewalls and roof. A silica ramming mix can be selected as an alternate for the bottom.

A most recent development in furnace design is the use of water-cooled panels in the sidewalls and roof which has reduced refractory consumption. Conversely the introduction of ultra-high powered, high production furnaces has lead to more severe furnace conditions requiring higher performance refractories.

The refractory industry has met this challenge with the introduction of pitch or resin bonded magnesite-carbon brick with or without antioxidants containing carbon levels of 5 to 30%.

The construction of a basic EAF begins with a high purity burned magnesite brick bottom or a combination of burned magnesite brick sub-hearth and rammed, cast or dry magnesite working hearth.

The lower sidewalls consist of burned magnesite plain or pitch impregnated. The slag line, depending on furnace conditions, can consist of direct bonded magnesite-chrome brick, or various qualities of pitch or resin bonded magnesite-carbon brick with carbon contents of 5 to 20%. The upper sidewalls are generally zoned to balance wear with the same products that are used in the slag line. The higher carbon contents usually go into the high wear areas (hot spots). The roof, if not water cooled, uses 70% alumina brick. The delta or area around the electrodes uses 85% alumina material either in brick form, ramming mixes, plastic, or precast castable shapes.

Furnace life varies too much to furnish specific figures, but generally a bottom with proper maintenance will last a year or more. Sidewalls with gun maintenance of magnesite or magnesite-dolomite products will last several weeks when the furnace lining is patched and put back into service. Complete relines occur every three to four months. Roofs that are not water-cooled generally are relined every one-to-two months.

Continuous Casting

There have been many changes in steel making over the years, but none has been as dramatic as continuous casting. This method of producing steel rods, bars and slabs is a simple process, but highly technical.

Basically, steel is produced separately in furnaces, and the hot metal is transferred to the continuous caster. From the caster, the hot metal continuously flows down a trough-like device (tundish) and is then continuously shaped into rods, bars or slabs, as shown on Page 28. This is much like the continuous float-melt process of glass tanks, except in the glass process, raw materials go in one end of the tank and finished glass flows out the other.

Refractories for the continuous casting of steel require a higher degree of functional diversity, performance and reliability than the refractories for most other steel plant applications.

Over the years they have proved practical for use with nonferrous metals as well. Continuous casting refractories' most important characteristics are summarized as follows. (1) High quality and performance reliability are absolutely vital. (2) Their life must be balanced with the other components in the casting system. (3) Installation, maintenance and demolition methods must be suitable for use with the continuous casting equipment. (4) They must not generate nonmetallic inclusions in the steel. (5) They must be available on a reliable supply basis.

The development of continuous casting processes for steel has paralleled the development of continuous casting of non ferrous metals. The continuous casting process allowed the continuous formation of steel billets or slabs which can be immediately rolled into finished shapes or sheet. The most recent developments in continuous casting have focused on improvements of internal quality of the cast product by decreasing internal segregation and non metallic-inclusion content.

This technology necessitated the development of new, extremely high quality refractory products to prevent refractory erosion and protect the liquid steel from reoxidation during this casting process.

Since the continuous casting process requires steel at higher temperatures and automated computer controlled liquid steel flow systems, flow control from steel ladles changed from stopper rod systems to slide gate systems. Special refractories have been developed to encase the molten steel throughout the continuous casting process thereby reducing reoxidation to a minimum.

Refractories for continuous casting start with the ladle lining and slide gate which are described separately. The molten steel flows from the ladle into a tundish which acts as a surge hopper, controlling steel-flow into the casters. Shroud tubes are used to encapsulate the molten steel as it flows out of the ladle into the tundish and from the tundish into the caster molds.

Continuous casting uses substantial quantities of refractories in the tundish, tundish flow-control device, and the shroud tubes for oxidation control between the ladle and tundish, and tundish and water-cooled mold. Tundish linings are changing from the long-life-style tundish, using high alumina products, to consumable liners made from periclase. This change was done to provide a clean contamination-free surface on the tundish on any start-up. The tundish flow-control devices require either alumina-carbon rods or external systems using high-alumina, alumina, or alumina-graphite materials. Shroud tubes are made from either fused silica or alumina graphite in a multiple of sizes and shapes with special features such as argon injection. The continuous-casting area requires many new refractories and a substantial number of them are based on imported bauxite or alumina from treated bauxite. Although not in substantial tonnages, many flow control devices and certain critical wear areas of shroud tubes may use zirconia or zircon as an essential component.

Steel Reheating Furnaces

The reheating furnace is used in the steel industry to provide an even temperature to an ingot, slab, or bar so that it can be rolled or pressed into a finished shape. An even temperature of 2100° to 2600°F (1150° to 1425°C) through the entire piece is necessary to obtain proper plasticity so that it can be worked into a strip, plate, bar, or angle. A large variety of furnaces are used for reheating. A typical example is the continuous pusher furnace.

The linings of these enclosures are made predominately of plastic refractories. Plastics provide monolithic construction for maximum fuel efficiency and longer overall life. The roofs and walls of these furnaces may use plastics ranging from super-duty grade to 90% alumina, depending on the severity of the temperatures and atmospheres to be used. Their life expectancies range from 4 to 8 years before replacement is necessary. The lower walls and floors are constantly subjected to molten slag attack and abrasion. Even the 90% alumina grade plastics require maintenance and replacement in 9 to 12 months. The exhaust areas such as hot air recuperator chambers, flues, and stacks employ a combination of plastics, castables, and brick construction and have a life of many years.

Foundry Furnaces

The foundry industry employs all classifications of refractories in several types of furnaces. The melting units, which use the most refractory materials, include cupolas, arc, and induction furnaces, as well as reverberatory and crucible furnaces. The particular type of refractory used depends mainly on the type of metal, slag chemistry (acidic or basic) and temperature of the metal being melted, as well as any erosion or abrasion that may be present. Types of refractories used include alumina-silicate, magnesia, high-alumina, mullite, clay graphite, silicon carbide, and zircon compositions. All forms including brick and shapes, castables, plastics and ramming mixes are used.

Foundry furnaces can be classified as fossil-fueled or electrically operated. The fossil-fueled furnaces include cupolas, which melt iron with coke in a verticle shaft, and reverberatory furnaces, which melt both ferrous and nonferrous materials. Cupolas are lined with firebrick and graphite and usually have sand bottoms. Reverberatory furnaces are usually box-shaped, lined with fireclay, high-alumina brick, and monoliths. Basic materials are used in some special applications.

The electric furnaces have either arc or induction supplied energy. Arc furnaces use either silica or magnesia walls and have high-alumina roofs. Coreless induction furnaces use silica, alumina, magnesia, or zircon ramming mixes. They have a current conducting coil completely encircling the vessel which transfers energy directly to the metal through electromagnetic induction. Channel types, which have the coil in a separate attachment and are joined to the main body of the furnace with a connecting channel, are lined with high-alumina, mullite, or magnesia materials, and have a lining life of up to three years. The channels are usually monoliths and can be relined separately from the body of the furnace. An induction furnace is shown on Page 29.

Copper Reverberatory

The reverberatory furnace is used in copper production to smelt ore or concentrates, to refine blister copper (a relatively pure form of copper) from converter furnaces, and to melt copper for casting or copper scrap refining. Individual furnaces perform only one of these functions. An example of this type of furnace is shown on Page 30.

As in the electric furnace, the operator has a choice of acidic or basic conditions and the refractories are selected to be compatible with whichever is chosen. Silica brick are resistant to acid slags and fumes while chrome-magnesite basic refractories are resistant to neutral or basic slags and fumes. High-alumina refractories are used when conditions are less strongly acid or basic.

Reverberatory furnaces are built for 50 to 300 tons of metal, depending on the available materials and the need for refining. With minor refining requirements, they also may be operated as continuous melting furnaces used, for example, to produce wire bars from electro-refined copper cathodes. Severity of service and intermittent or continuous operation dictate the schedule for major repairs or rebuilding. A one-to-two year service life is typical.

Copper Converters

The copper converter is a furnace designed to process copper sulphide (matte) from a reverberatory smelter into blister copper by blowing air through the molten metal. As shown on Page 31, the converter is cylindrical and handles up to 100 tons of metal at a time. The lining is basic brick, either magnesite-chrome or chrome-magnesite, selected by the copper producer to best fit the materials and ores with which he is working.

Recent experiments with oxygen-enriched air for blowing has boosted the temperature experienced by the refractories indicating the need for a higher-purity magnesite composition. The blowing produces considerable turbulence in the molten metal and the service life of these linings seldom exceeds 90 days. At that point, major repairs are usually required, although complete rebuilding may be unnecessary for several years.

Glass Melting Furnaces

Unlike many metallurgical processes, the melting of glass is almost always a continuous process. Raw batch materials like silica sand, soda ash, lime, etc., are fed into one end of the furnace while glass is drawn off at the opposite end. Glass-melting tanks typically operate at temperatures of 2732-2912°F (1500-1600°C) during the entire three-to-five year period between repairs.

Also, unlike other metallurgical processes, the refractory corrosion products are not "tapped off" with the slag. Any defects, "stones" (pieces of refractory), "cords" (usually as clear striations) or "blisters" (gas trapped bubbles), introduced by the refractory remain in the products where they not only affect its beauty or aesthetics, but can also adversely affect critical use properties like strength or freedom from optical distortion.

The type of refractory used to contain the molten glass, therefore, is strongly dependent on the glass composition, its melting and forming temperatures and the product quality required.

The common soda-lime glasses (used for bottles, everday tableware and for window glass) and many other specialty glasses (like lead crystal, light bulbs, television tubes, borosilicate laboratory glass, etc.) are melted in tanks with high-purity, fusion-cast alumina-zirconia-silica (AZS) sidewall refractories. Fusion-cast alumina sidewalls may be used in cooler zones and foreheaths. Refractory bottoms are built up in layers ranging from insulating- to high-duty and super-duty fireclay refractories supporting subpavings of zircon or rebonded fused AZS with fused AZS, fused alumina or sintered zircon-alumina pavings in glass contact. This heavy construction is necessary to avoid burnout through the bottom that could release hundreds of tons of molten glass onto the floor beneath the tank.

Insulating fiberglass is an especially corrosive high-alkali borosilicate glass. Fusion-cast chrome containing sidewalls and fusion-cast chrome or AZS bottoms are required to contain it.

The forming of continuous-filament E-glass used for fiberglass reinforcement and textiles is especially defect-sensitive. Sidewalls of isostatically-pressed or slip-cast dense chromic oxide provide the optimal resistance to corrosion and the potential defects that could result. Bottoms, backup, and foreheath refractories are typically lower-density, coarse-grained chromic oxide or dense zircon compositions.

The majority of melters are natural gas- or fuel oil-fired regenerative furnaces. In a regenerative furnace, like the glass container tank shown on Page 32, hot exhaust gases are passed through an open refractory packing or "checkerwork", thereby heating it. Subsequently, the combustion air can be pre-heated by passing it through these checkers to recover the heat stored in them. This is accomplished by having two regenerator settings. One setting is heating the combustion air while the other is being heated by the burner exhaust. The direction of airflow and firing are then periodically reversed.

The regenerator crowns, upper sidewalls, and upper checkerwork are usually built of basic brick. Usually, the lower sidewalls and, sometimes, depending on the severity of the service conditions, the lower checkers are made of super-duty firebrick. Special thin-walled basic or fused AZS checker shapes, designed for optimal thermal efficiency, are becoming increasingly common.

The melter crowns of most fuel-fired furnaces are built of silica bricks. The breastwalls, port necks and other components of the furnace superstructure are most often made of fusion-cast AZS, fusion-cast alumina, sintered zircon-alumina and silica refractories. In continuous-fiberglass applications, mullite crowns and breastwalls are common because operating temperatures approach or exceed the limits of silica refractories.

In smaller furnaces, and those melting E- fiberglass, direct fuel-firing, accompanied by recuperative heat exchange is more common than regeneration. In certain glasses, e.g. insulation fiberglass, lead crystal, and certain borosilicates, electric melting effectively controls the emission of toxic or corrosive vapors. Electric melting is also extremely energy-efficient, especially if unmelted batch can be used to insulate the top surface of the melt. Since recuperative and electric furnaces have no regenerators, they may use as little as ⅓ the mass of refractories of a regenerative furnace with identical capacity.

One application unique to glass-melting is the use of tin oxide refractory electrodes, primarily for the electrical melting of lead-containing optical and fine crystal glass or for low-power forehearth boosting. These nonmetallic electrodes double as part of the refractory wall, and need not protrude into the glass.

KILNS

Kilns are specialized pieces of equipment for exposing nonmetallic mineral materials to various temperatures. The heat may be applied merely to drive moisture from the products, or it can be used to produce a particular chemical reaction, or to bring a change in crystalline structure. Heat-promoted chemical reactions include the elimination of carbon dioxide from calcium-aluminum-silicates to form Portland cement, and the conversion of aluminum and magnesium hydrates to their oxides, known as alumina and magnesia. Kilns are also used to process refractory raw materials and other common products such as sanitary- and dinnerware. In each of these cases, a specific amount of energy must be used to force the reaction to conclusion.

Vertical Shaft Kilns

The vertical shaft kiln was originally developed as a means for holding materials such as limestone in place while the heat of a fire underneath drove off the carbon dioxide to produce lime. From that crude beginning, the equipment has evolved so that it is capable of accepting a continuous feed at the top, producing the desired chemical reaction during its descent, and eventually discharging a product from the base for subsequent cooling and handling. Temperatures from 1500° to 1652°F (815° to 900°C) are needed at the center of a piece of limestone to produce the desired reaction. This means that the operating temperature in the lime kiln will be at least 2012°F (1100°C).

Service life for a vertical shaft kiln burning limestone ranges from around 9 months to several years. Abrasive wear from loading, and spalling, and lime reaction in the hot zone are the primary causes of refractory consumption.

Shaft kilns are also used for sintering iron ore pellets and for making tabular alumina.

Typical shaft lime kilns are not as prominent as they used to be. Today, they represent less than ten percent of total United States' production.

Rotary Kilns

A rotary kiln, considered as one of the most important kiln type, is basically a vertical shaft kiln placed on its side, but tilted at a slight angle so that its rotation and gravity aid the flow of material from the charging end to the discharging end of the tube. Page 33 represents a lengthwise view and several cross sections of a typical rotary kiln. Rotary kilns compete with vertical shaft kilns in the production of lime and dolomite lime. The principal advantage of the rotary kiln is its high rate of production, up to 70 tons per hour.

Rotary lime kilns vary from 8 to 15 ft. in diameter and from 125 to 450 ft. in length. Inside the steel shell is a refractory lining that may be from 6 to 9" thick, usually of super-duty, basic, dolomite or high-alumina brick in the burning zone at the discharge end for a length of about 30 ft. Regular duty firebrick or castable refractories are used throughout the rest of its length. The high throughput level means that the hot zone on the burning end is hotter than in a vertical shaft kiln, often as high as 2600°F (1425°C).

Rotary kilns in the United States are also used to make Portland cement, which is basically calcium aluminum silicate formed by a sintering reaction. Limestone, clay or shale, and sand are ground into a uniform mixture and charged continuously to the feed end of the kiln. The reaction is completed as the mixture passes through the kiln, and the sintered product (called a clinker) is ground with additives to form the type of Portland cement desired. The temperature at the hot or burning end of a cement kiln is substantially higher than that required for lime. The cement reaction takes place at 2750°F (1510°C) or higher and the hot zone usually runs as high as 2912°F (1600°C).

In the past 10 years, new cement kilns have been getting larger, both in diameter and length, to increase their production rates. Recent installations in this country range from 14 to 25 feet in diameter, and up to 760 feet in length. The basic construction consists of a steel outer shell within which is the refractory lining. In the burning zone, the lining is basic brick; dense regular firebrick or castables are used at the feed end.

The mammoth kilns are capable of producing 125 tons or more of cement clinker per hour – more than a million tons per year. Cement kiln linings have service lives ranging from 6 months to 1½ years before major repairs are required and up to ten years before complete relining is necessary.

Other products processed in rotary kilns include: alumina used to make aluminum metal, as well as refractories; clay, bauxite, magnesia and dolomite for refractory use; and titanium dioxide used for paints and plastics. In these applications, the life of the refractories is in the range of one-to-three years.

Tunnel Kilns

Tunnel kilns are long, open-ended, refractory lined chambers, through which ceramic products pass on kiln cars. Tunnel kilns are the continuous method of firing (burning) ceramic products such as sanitaryware, structural clay, common face brick, roof tile, electrical insulators, spark plug bodies, wall tile, dinnerware, pottery and refractories. These products pass through a preheating zone to a burning or vitrification zone and finally through a cooling zone of controlled temperatures to the exit. High volume production, fired at the same temperatures for product uniformity, and low fuel consumption compared to a shuttle kiln are predominant characteristics of a tunnel kiln operation.

Depending on the product being fired, the temperature in the hottest zone of a tunnel kiln will range from about 1900°F to 3400°F (1040° to 1870°C). Page 34 shows an isometric view of a typical kiln used to fire high temperature refractory products. The heat for the firing process is supplied by gas/oil burners usually mounted in the sidewalls of the kiln. Burners can be arranged in either an over/under pattern (low temperature firing) or an index pattern (lane firing) as shown on Page 34. The exhaust gases generated in this burning zone are pulled through the preheating zone by a large exhaust fan located near the entrance of the tunnel kiln. Air used for cooling the product is reused as combustion air required by the burner operation.

Tunnel kilns can range in length from 50 to 600 feet. For the hot zone of the kiln, the refractory quality, depending on temperature requirements, range from super-duty to high alumina to basic to fused cast alumina. Roof construction may use similar material. Insulating brick of various service temperatures is used as a backup; however, many of the tunnel kiln roofs are silica brick. For maximum heat conservation, loose insulation or fiber blanket usually make up the outside layer of insulation.

Shuttle Kilns

Shuttle kilns are refractory or fiber-lined chambers, closed by movable door/s (Page 35), in which ceramic products are fired in place, using a predetermined firing curve (batch operation). The product is usually placed on kiln cars (car bottom type) that make possible the handling of the green or fired product outside the firing chamber. In comparison, periodic beehive kilns are loaded and unloaded manually making it necessary for operating personnel to enter the firing chamber.

While tunnel kilns favor the firing of similarly sized pieces and types of refractory compositions because it is a continuous operation, a shuttle kiln can handle a wide variety of product sizes, refractory compositions and load arrangements. This is made possible because the firing operation is cyclic in nature, and different firing curves can be programmed into the kiln's monthly operations. Shuttle kilns have been used to fire the larger special shapes that need the longer firing cycles as compared to smaller standard refractory sizes. Shuttle kilns also handle lower volumes of production which would not be economical to fire in the continuous process of a tunnel kiln.

Car bottom type shuttle kilns usually contain from 1 to 4 cars, but many shuttle kilns have been built that contain more. The larger a shuttle kiln becomes, the more the production rate of that kiln will approach the production rate of a continuous firing tunnel kiln operation.

No matter which type of kiln, the refractory lining is selected based upon the material being fired and the maximum kiln temperature required. Desired characteristics of the lining include spall resistance, volume stability, and good insulating qualities. In special cases, kiln atmospheres other than normal combustion gases may dictate special considerations with regard to linings. High temperature firing requirements utilize the high alumina type refractory with suitable insulating backup. Lower temperatures can utilize insulating brick or ceramic fiber or a combination of both. Because the refractory lining experiences repeated heat up and cool down with every firing cycle, refractory life is harsh and spalling can be expected. The life of a lining, dependent upon the rate of spall, the temperature levels achieved, and the firing atmosphere, is counted in kiln cycles rather than years.

Low-Mass Kiln Cars

The energy crisis of the 1970's drove an energy intensive ceramic industry to demand application of new fuel savings measures. Prime targets for such measures were the shuttle and tunnel kilns used in the everyday operation of the ceramic manufacturer's plant. The ensuing years saw particular attention to recuperating stack losses, improved combustion systems, better insulation, and reducing the high thermal energy requirements of heavy-mass kiln cars.

Pre-1975 kiln car designs used large amounts of hard refractory (pyrophyllite fireclay, alumina, etc.) to protect the steel kiln car frame from the heat of the kiln. This material often outweighed the weight of the product being fired and in many cases, dictated the firing curves required of the kiln itself. Large amounts of fuel were expended trying to fire this mass.

Kiln designers and kiln furniture manufacturers responded with new and various arrangements of reduced mass refractory car tops and support structures. Combinations of hard refractory, insulating brick, and ceramic fiber or insulating powder have been used. The most dramatic fuel savings were achieved by the almost total use of ceramic fiber with only enough refractory (cordierite, alumina and silicon carbide, etc.), posts and beams or deck slabs to support the load being fired. Currently available ceramic fiber generally limits application of all fiber construction to below 2700°F kiln firings.

The most dramatic applications of the new fiber designs have been in the whitewares and tile industries when fuel consumptions have been slashed by about 50%. Fuel savings in the refractory industry are generally less because of lower product to car refractory weight ratios. Other benefits have included reduced maintenance, improved uniformity of firing and reduced firing cycles.

Petrochemical Industry

Service conditions of high heat, corrosive atmospheres and erosive streams carrying abrasive particles require the use of refractories in a variety of locations in refineries and petrochemical plants. These refineries and plants have a variety of locations where process temperatures of 1000°F to 3000°F (538°C to 1650°C) must be contained. Many of the applications are simple heat enclosures such as furnaces and flue gas ducts that demand a wide choice of refractory designs. Other areas such as cyclones and slide valves present difficult service conditions that require careful material selection and engineering design.

Fluid catalytic cracking units, ammonia plants, naphtha reformers, pipestills and pre-heater furnaces must have appropriate linings to protect vessel and furnace walls from process conditions involving heat, corrosive atmospheres and wear. Refractory concretes are often the best lining materials to resist these conditions.

The use of refractory concrete was a significant step in improving the life of refractory linings. Early designs frequently used a layer of lightweight insulating refractory next to the shell to reduce temperatures, and a layer of dense, high strength concrete (often held in hexagonal steel mesh) to resist the physical action of fluidized catalyst beds and high velocity gas streams with entrained particles. The use of hexagonal steel grating is both expensive and time-consuming, since it involves bending the steel to the desired radius and welding it to studs that have been fastened to the shell.

The current design used in many areas is a single layer of semi-insulating refractory concrete with insulating and strength properties midway between the lightweight and dense products. Available refractory concretes cover a variety of types: insulating, semi-insulating, dense high strength and erosion resistant. Repair work often uses either alkali silicate or alumino phosphate bonded material.

While refractory concretes constitute the largest volume of refractory materials used in refining and petrochemical operations, other refractories such as brick, plastic and ceramic fiber have been used effectively.

Refractoriness is seldom a crititcal factor, and the selection of a lining material is usually based on such factors as wear resistance, thermal conductivity, strength and the ability to resist such elements as steam, hydrogen, acid condensate and other corrosive media. Economy and ease of placement may be determining factors in some cases. An example of a petroleum reactor vessel is shown on Page 36.

VII. FUTURE

It is difficult to predict the future of any industry with any real degree of accuracy. It is safe to predict, however, that there will continue to be a refractory industry. The size and shape of this industry will be determined by the evolutionary changes in both the domestic and world basic industries.

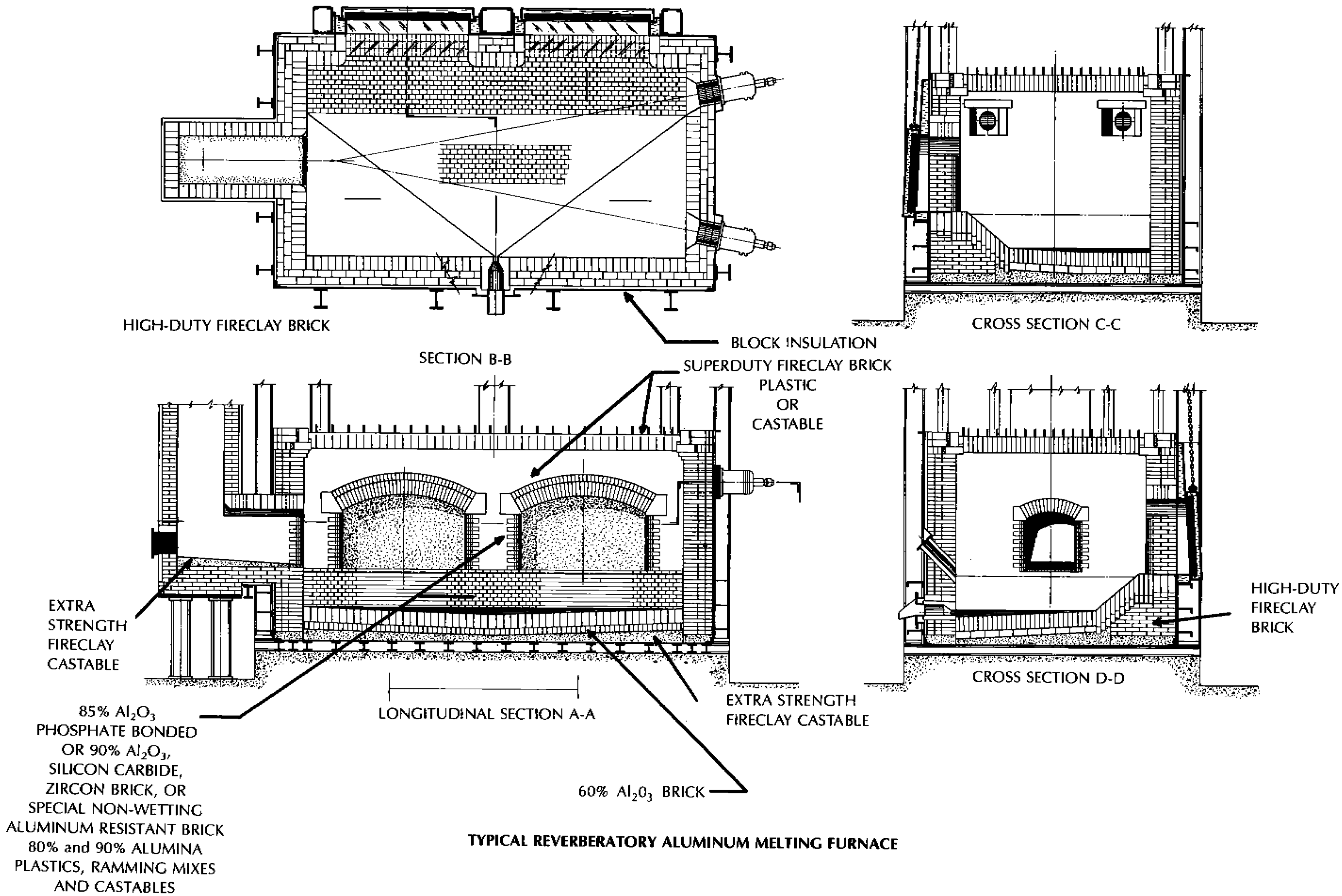
There will always be a need for hot metals, foundries, glass, steel products and the new growth industries (high technology ceramics). One industrial sector that has seen many changes is utilities, where electrical generation has switched from coal-fired boilers, to oil, and back to coal. This industry has seen as many changes as large-scale incineration. Many cities used to burn refuse, then changed to landfill elimination. Now, there is a resurgence of incineration since there is a benefit to regenerating power this way, in addition to, the elimination of garbage. So with two very traditional, mature industries, there is an ever-demanding need for new and better refractories.

Thus, the future of refractories continues much in the same mode as it began, some thousands of years ago. As man forever progresses, and industry builds and creates, heat is used. When heat is involved, sooner or later there is a need to retain and control it, and refractories continue to expand their critical role in the future growth of basic industry.

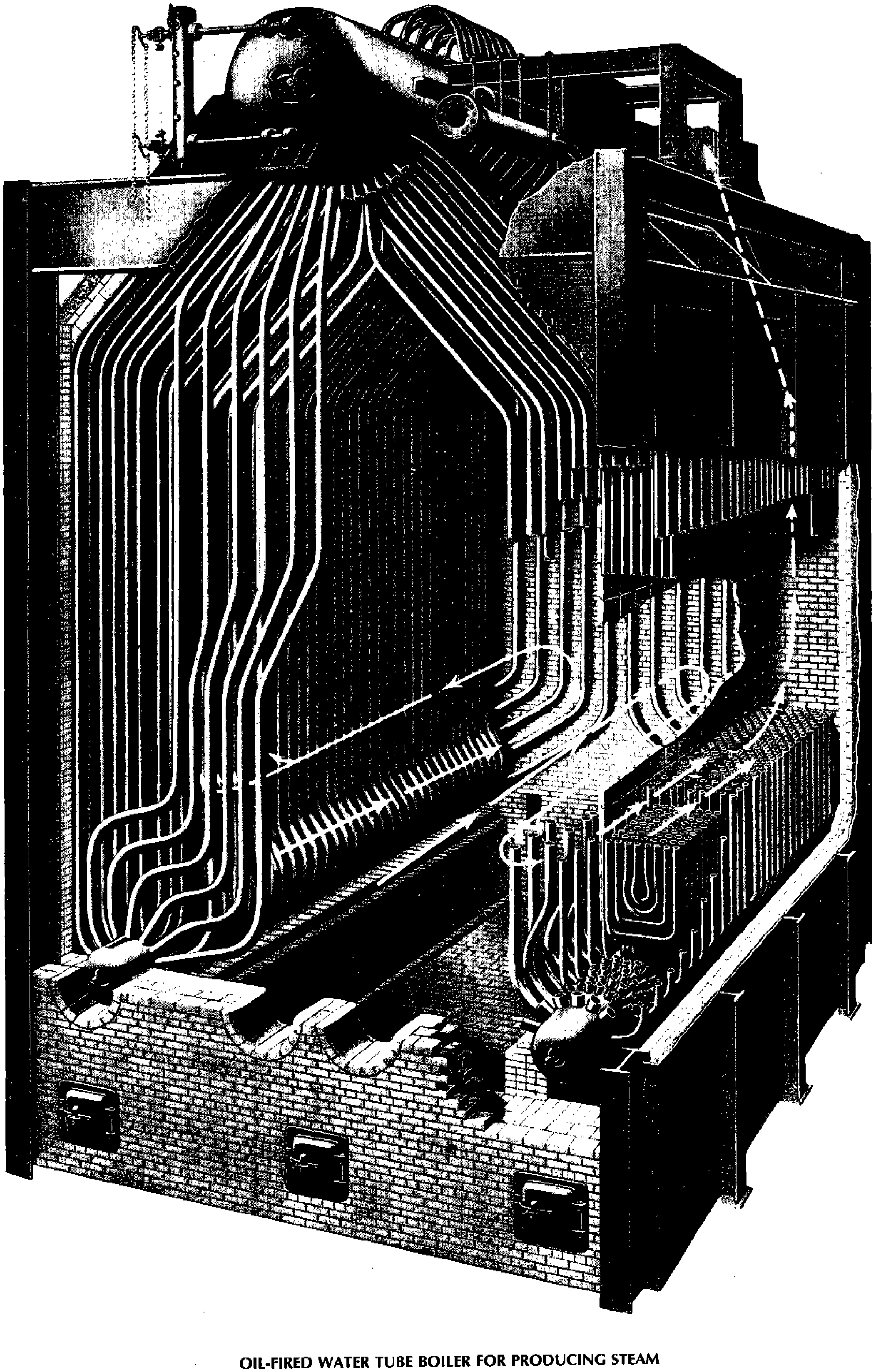
VIII. EPILOGUE

This has been a general view of refractories. Each refractory manufacturer publishes literature regarding the specific properties and applications of its refractories' unique properties. Also many volumes of information are available on every subject mentioned, from raw materials selection, to manufacturing processes, to methods of application, to evaluation of results.

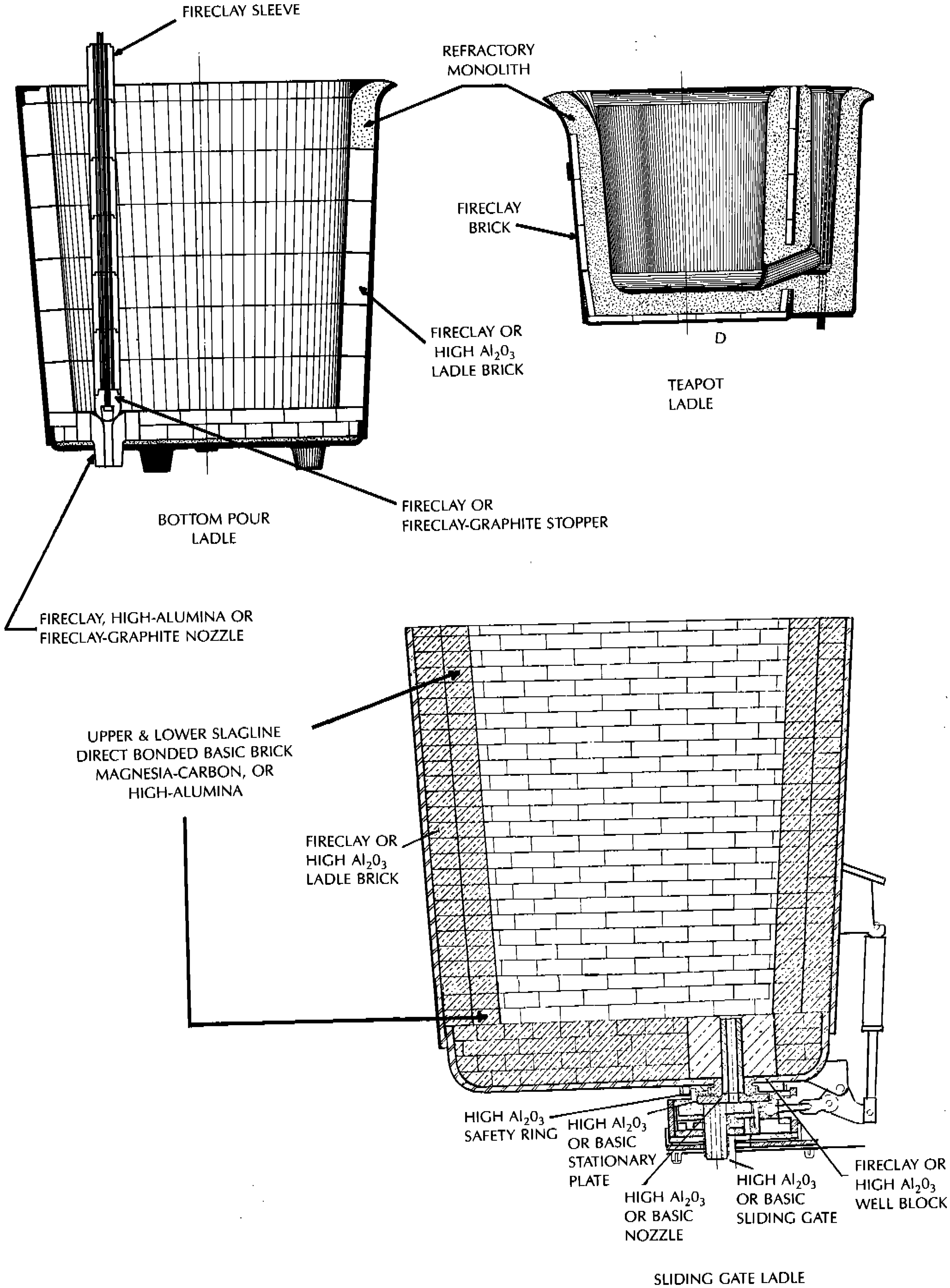
The consumer's prime requirement of our industry is that the refractories, so vital to a variety of manufacturing processes, be available and capable of doing the required job. To achieve this goal, the refractory industry strives to provide the necessary serviceable refractories through selection of raw materials, manufacturing process control, production analysis, structure design, and constant evaluation of results. Without refractories modern industry could not exist.



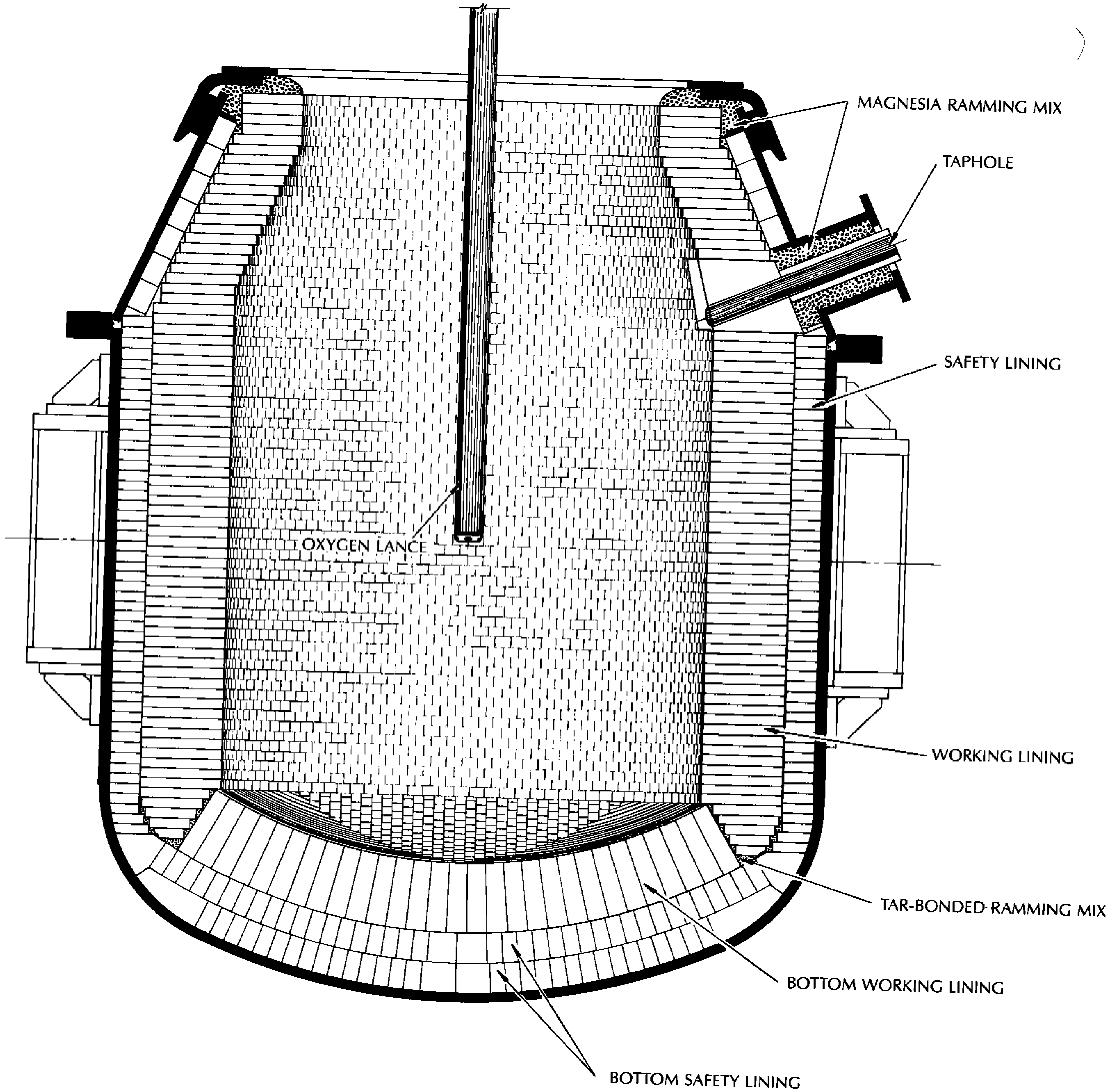
TYPICAL REVERBERATORY ALUMINUM MELTING FURNACE



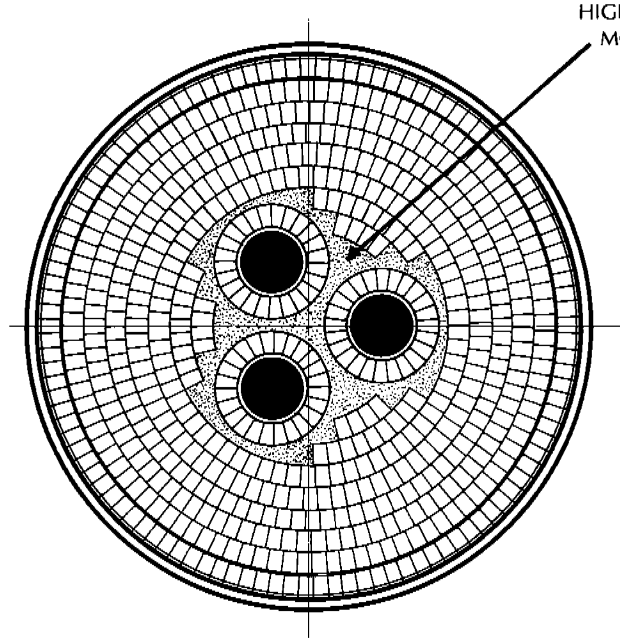
OIL-FIRED WATER TUBE BOILER FOR PRODUCING STEAM



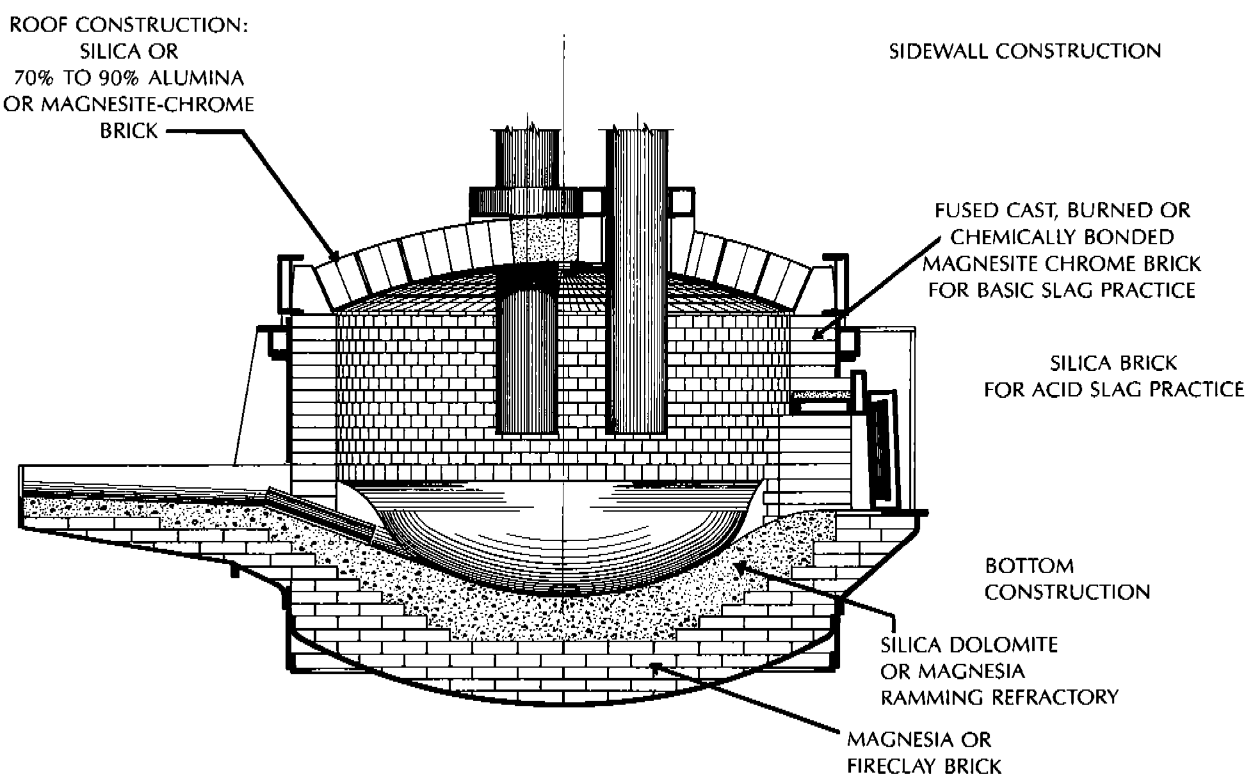
THREE TYPES OF LADLES: BOTTOM POUR, TEAPOT AND SLIDING LADLE



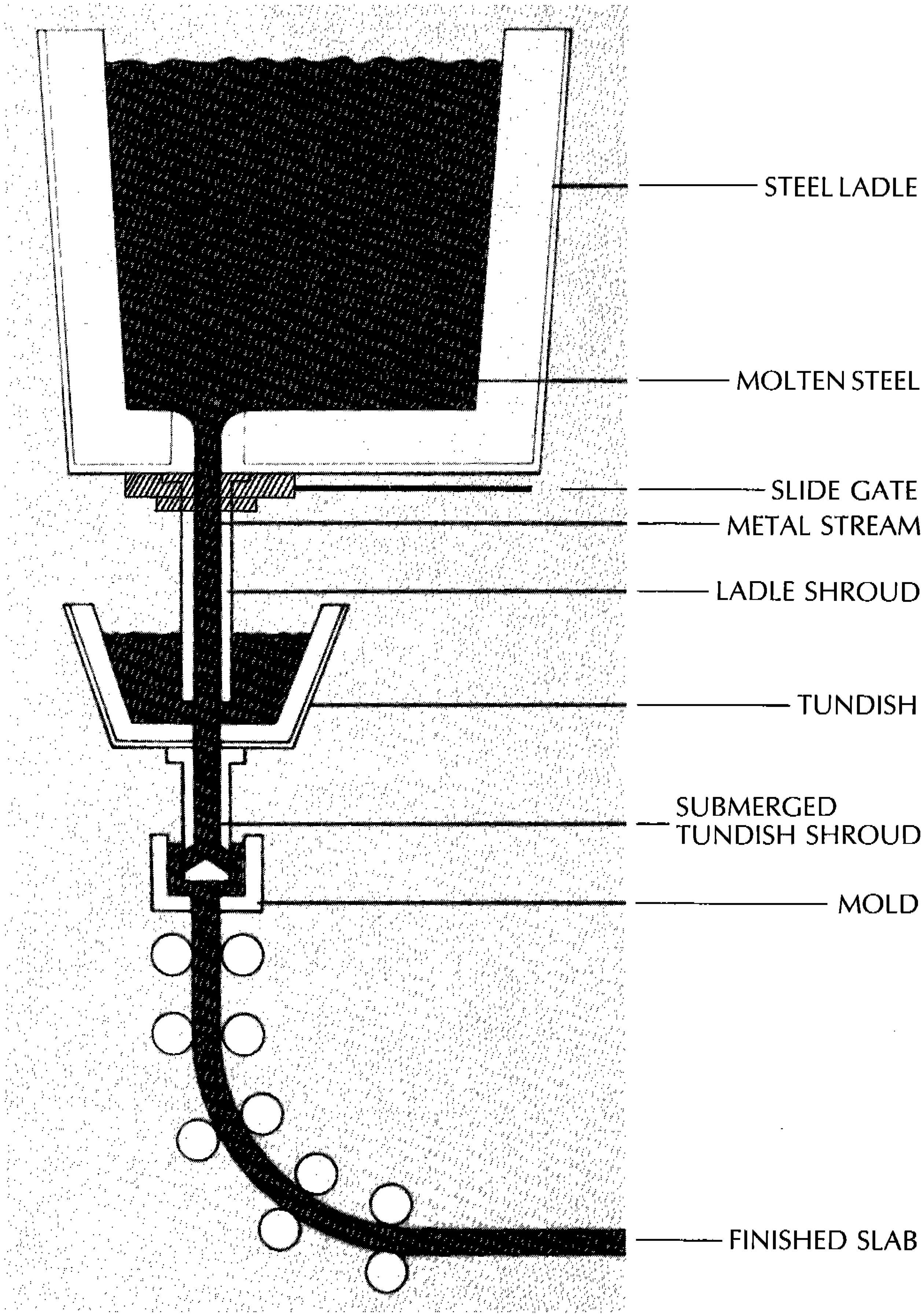
BASIC OXYGEN FURNACE FOR PRODUCING STEEL – TOP BLOWN



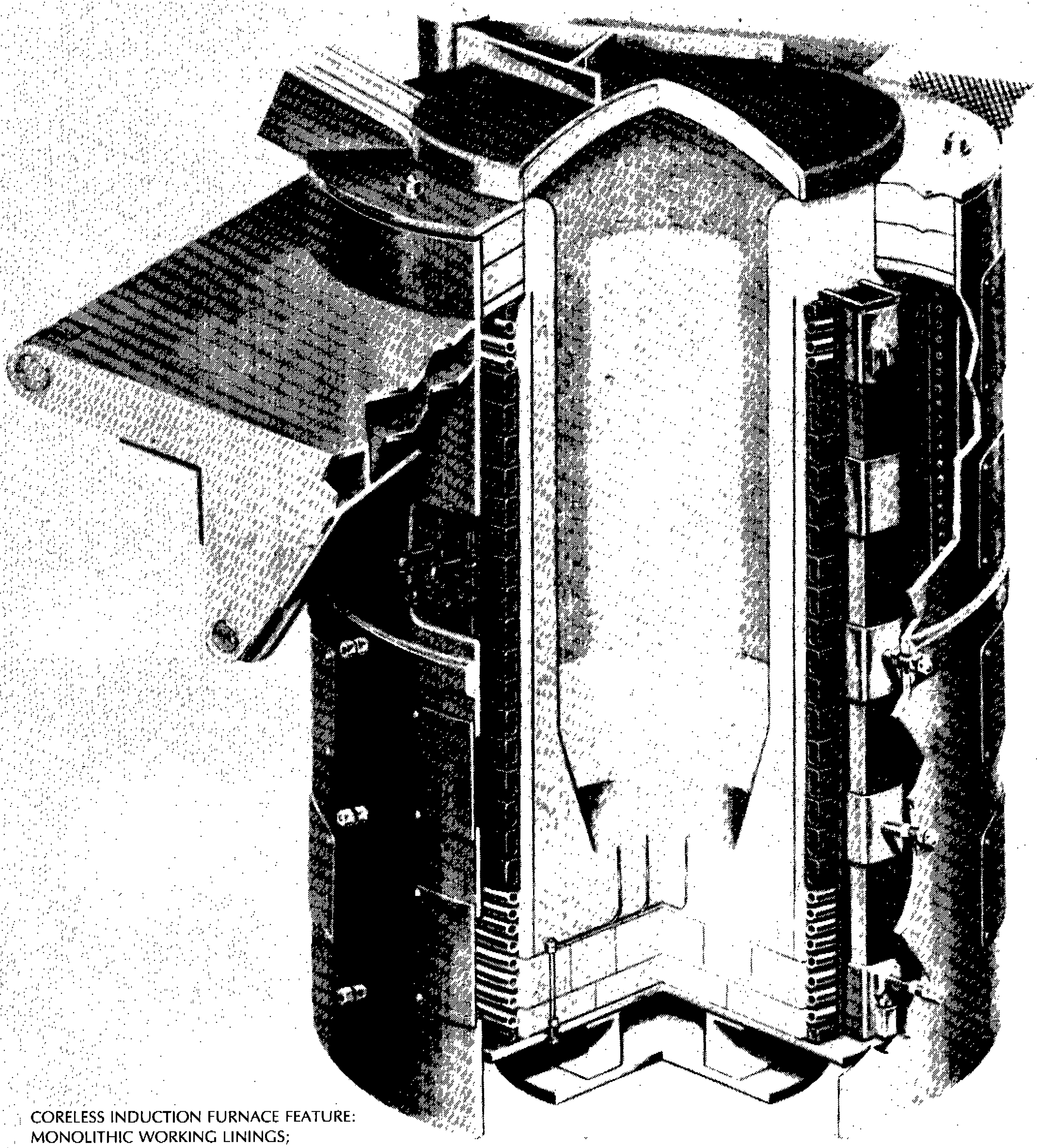
ROOF CONSTRUCTION



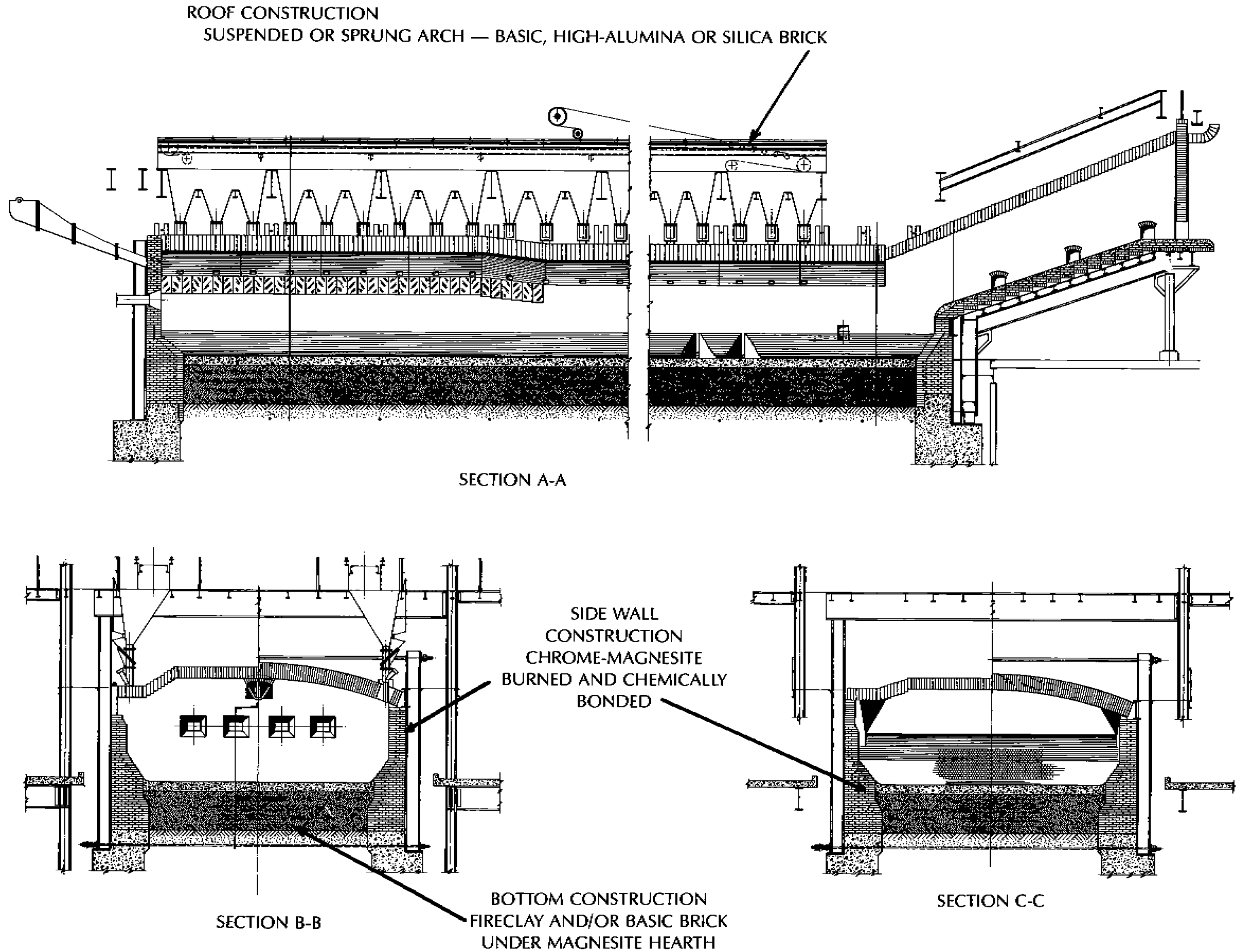
TYPICAL ELECTRIC ARC FURNACE FOR STEEL PRODUCTION



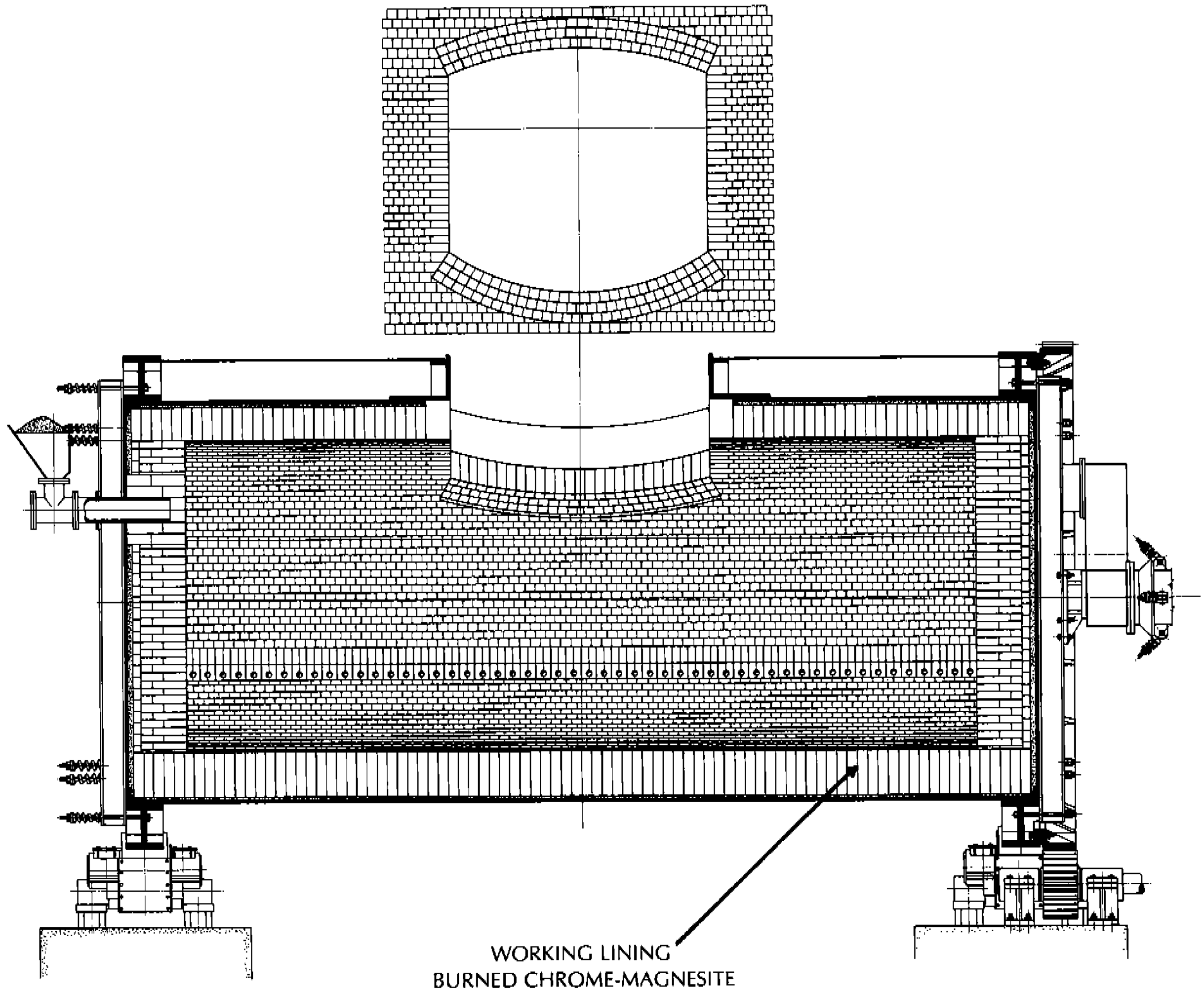
THE PROCESS OF CONTINUOUS CASTING BEGINS IN THE LADLE AND ENDS WITH THE STEEL ROLLED INTO A FINISHED SLAB

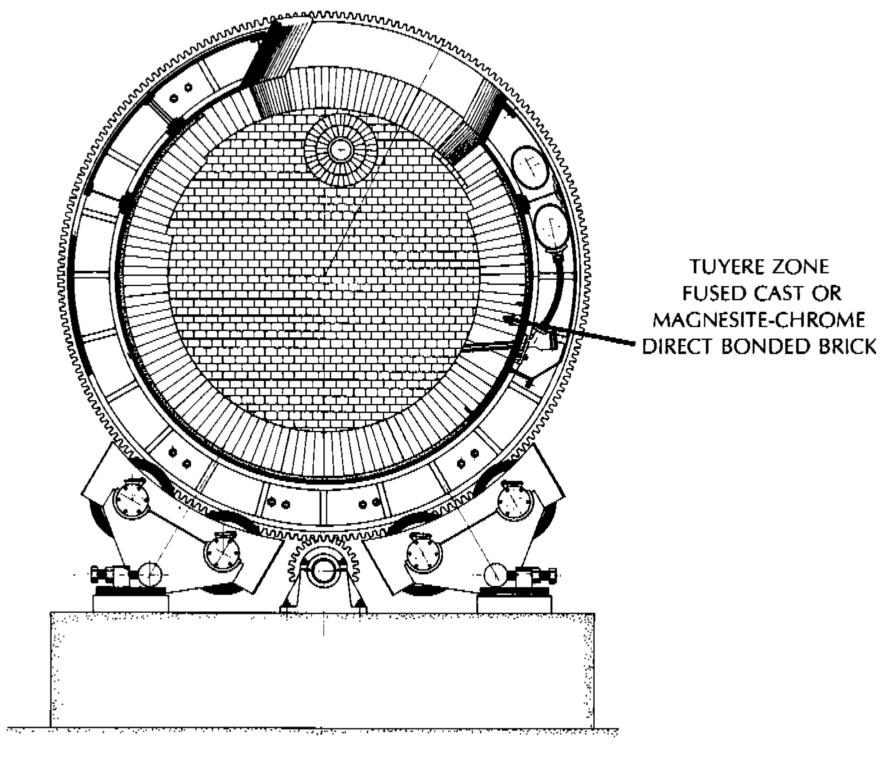


CORELESS INDUCTION FURNACE FEATURE:
MONOLITHIC WORKING LININGS;
MONOLITHIC POURING SPOUTS;
BRICK LININGS FOR LARGER FURNACES;
AND MONOLITHIC COVERS

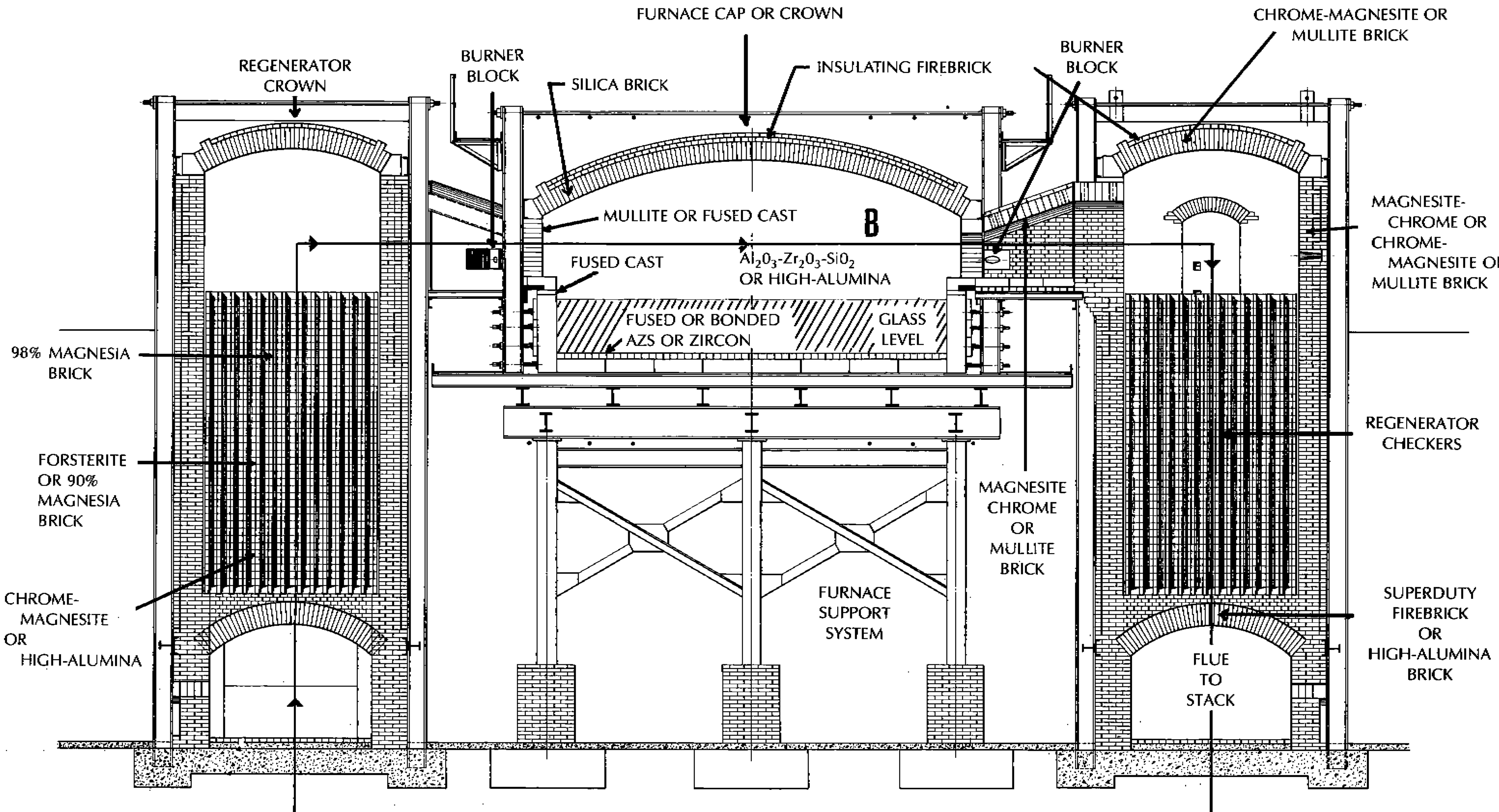


TYPICAL COPPER REVERBERATORY FURNACE



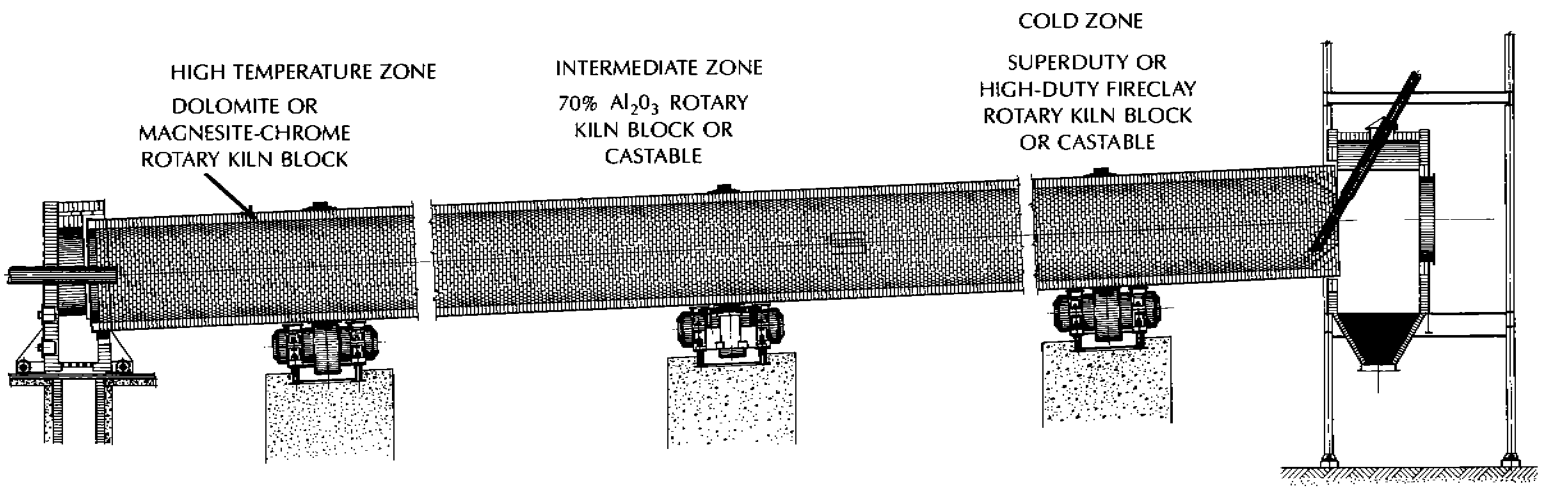


TYPICAL COPPER CONVERTER

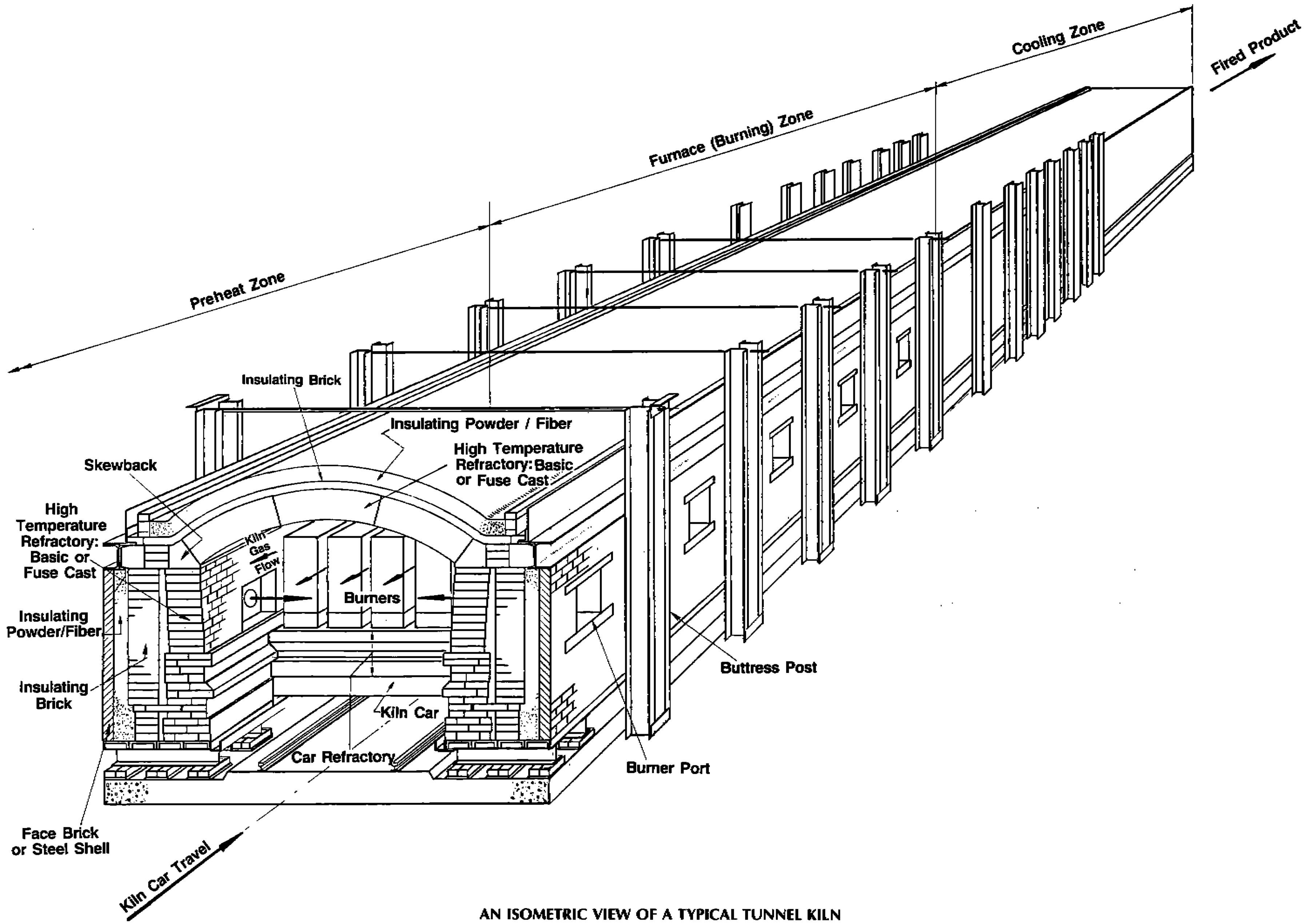


In the figure above, the gas and heated air enters from the side of the rectangular shaped furnace (A.). Raw materials are injected into one end, air is drawn into regenerator sections along side the tank, and with ignited gas, enters the furnace through burner blocks. The flame goes into the furnace across the top of the glass batch (B.), and exhaust gases are withdrawn via the port through the regenerator (C.), and out the chimney flue. After about 15-20 minutes of this cycle, the direction of the gas and air is renewed in the opposite direction. The cycle continues to repeat itself, and the alternating burning cycles keep the air mixture heated, allowing more efficient use of the gas in the furnace.

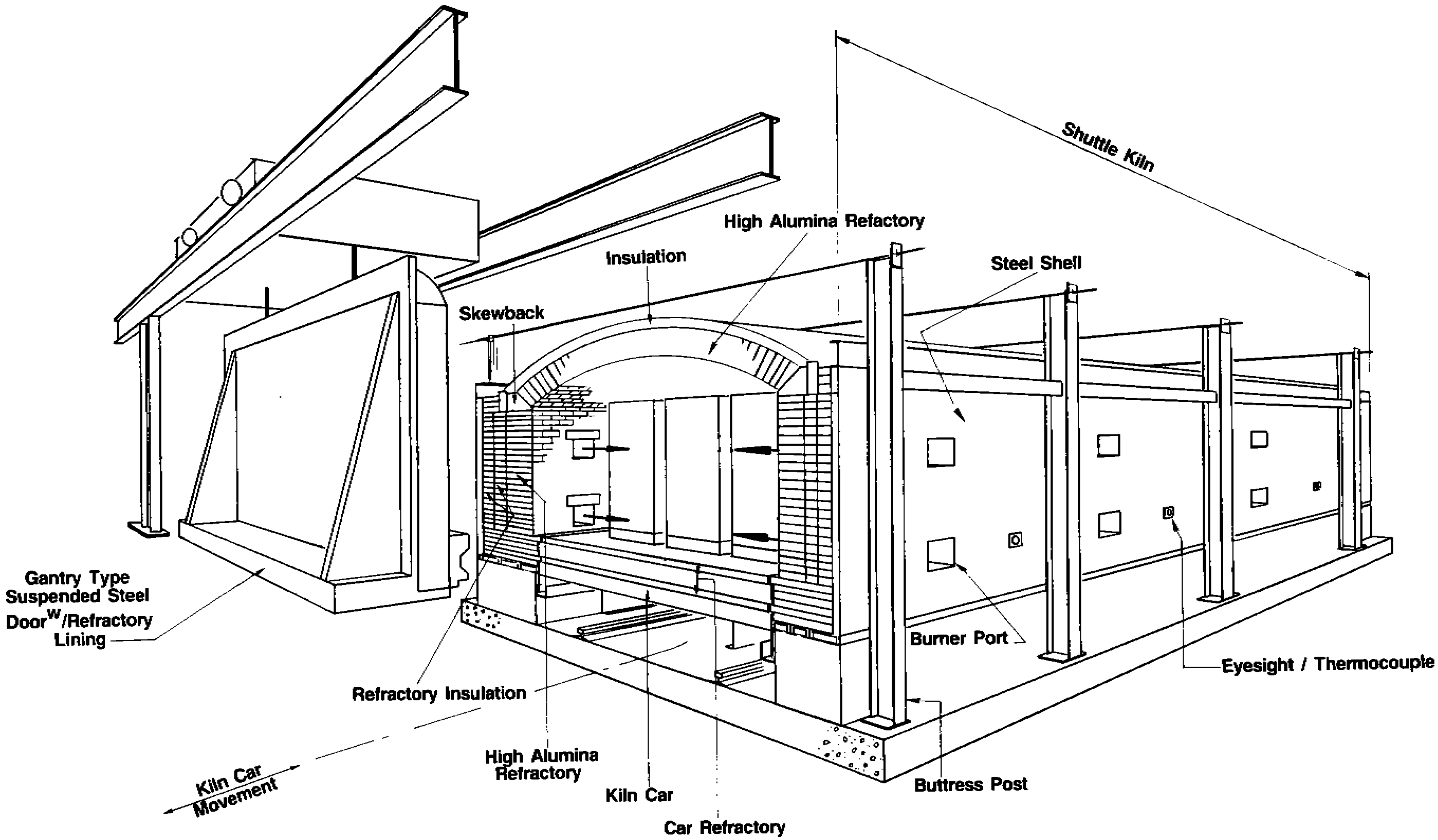
CROSS-SECTION OF A TYPICAL REGENERATIVE SIDEPORT GLASS TANK MELTING FURNACE



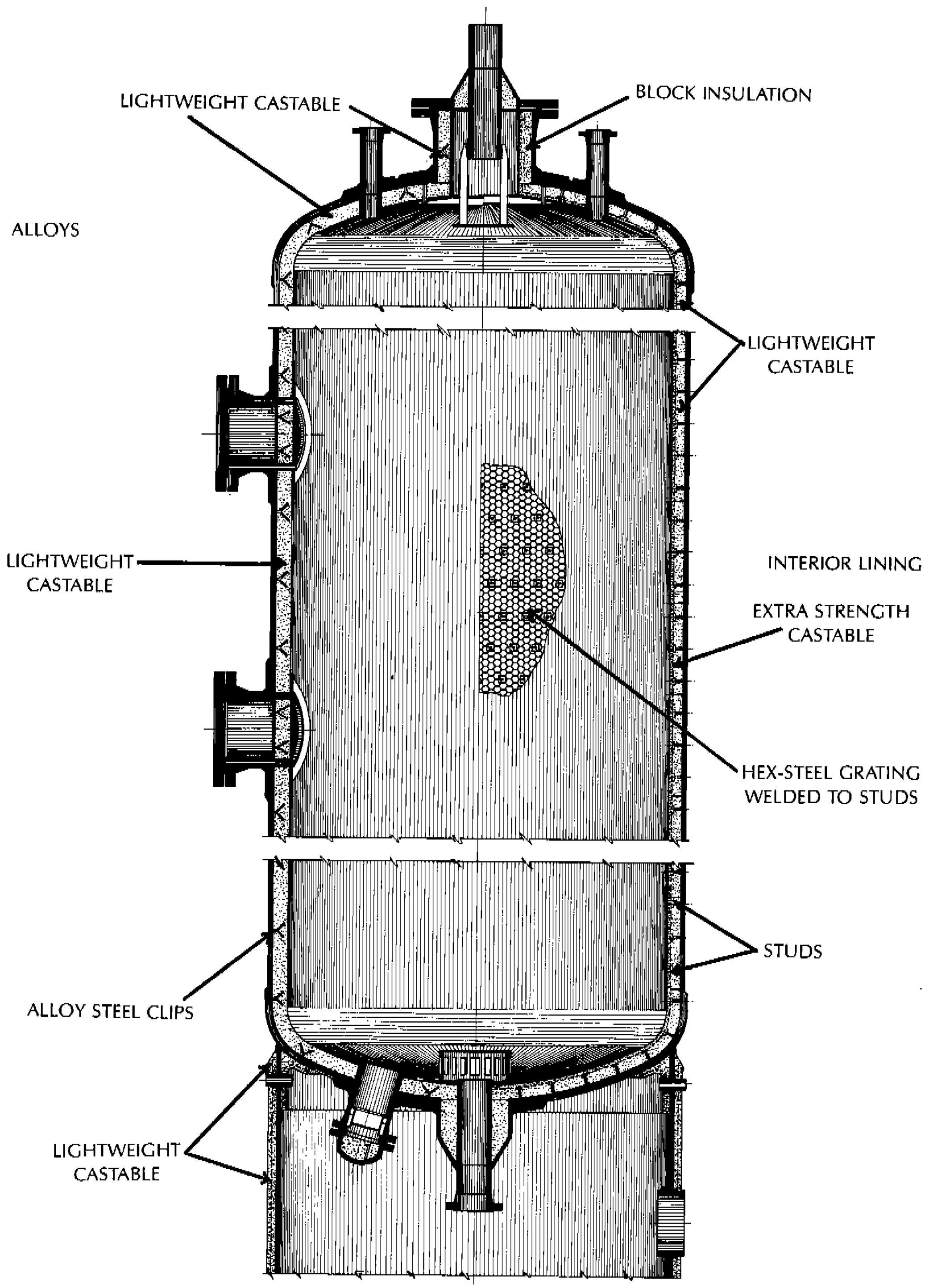
A VIEW OF A TYPICAL ROTARY KILN



AN ISOMETRIC VIEW OF A TYPICAL TUNNEL KILN



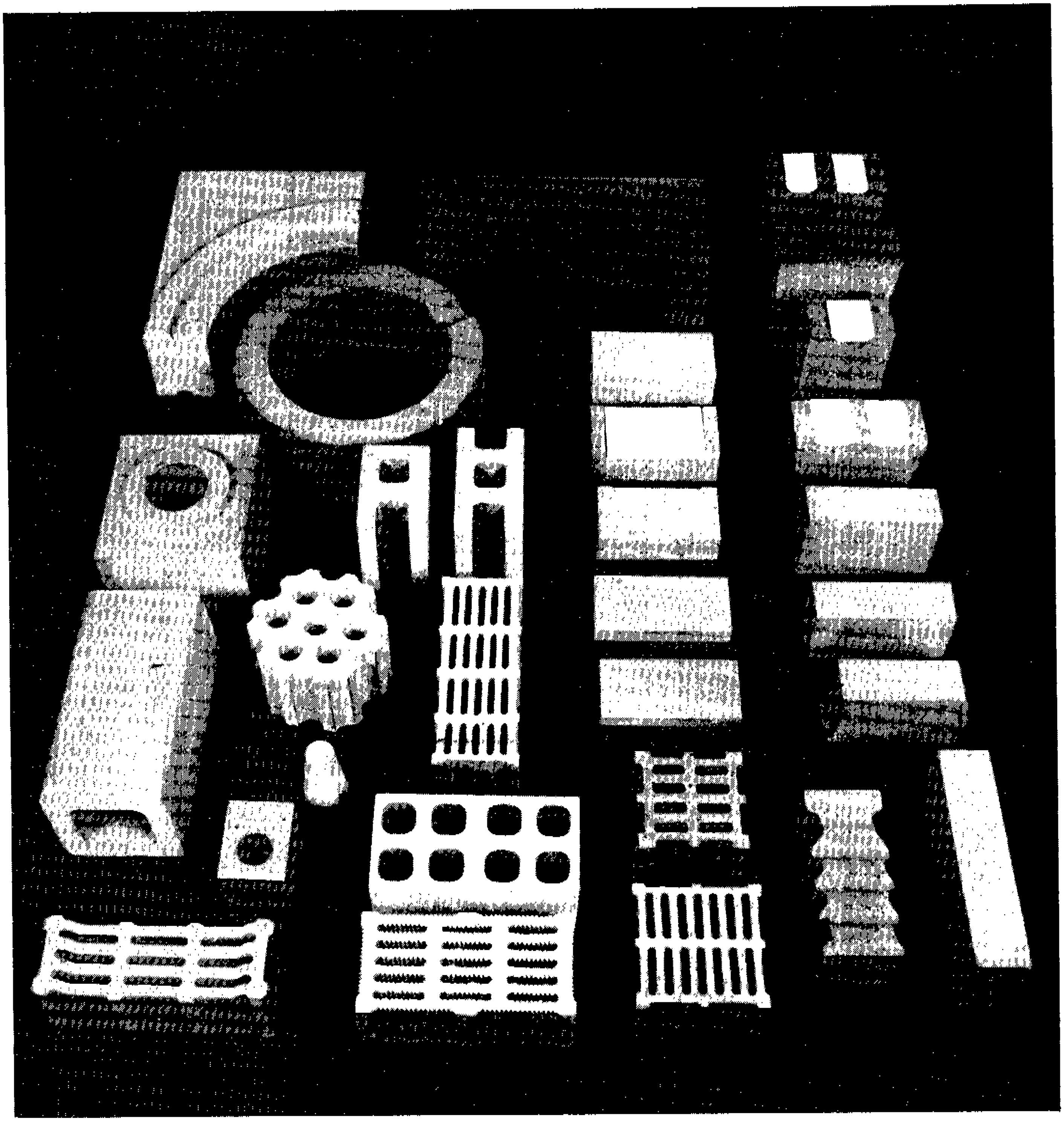
AN ISOMETRIC VIEW OF A TYPICAL SHUTTLE KILN



NOTE: LEFT HALF SHOWS INSTALLATION USING ALLOY STEEL CLIPS; RIGHT HALF HEXAGONAL STEEL GRATING WELDED TO STUDS.

TYPICAL PETROLEUM REACTOR VESSEL

Appendix 1
Brick and Shapes



Appendix 2
Selected Bibliographies

American Ceramic Society, (Columbus: American Ceramic Society).

Annual Book of ASTM Standards, Volume 15.01, "Refractories: Carbon and Graphite Products; Activated Carbon" (Philadelphia: American Society for Testing and Materials, published annually). See volume entitled **Index** for complete refractory listings.

Brick & Clay Record (Chicago: Cahner Publishing Company).

Chesters, J.S. **Refractories Production & Properties** (London: Iron & Steel Institute, 1973).

Crookston, James A. and William D. Fitzpatrick, "Refractories" in Stanley L. Lefond, Editor-in-Chief, **Industrial Minerals and Rocks** (New York: American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., Fifth Edition, 1983), pp. 373-385.

Dana, James Dwight. **The Manual of Mineralogy** (New York: John Wiley and Son, Seventeenth Edition, 1959).

Fisher, Robert E., ed. **New Developments in Monolithic Refractories**, Volume 13, **Advances in Ceramics** (Columbus: American Ceramic Society, 1985).

Gilchrist, James Duncan. **Fuels, Furnaces and Refractories** (New York: Pergamon Press, 1977).

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Lankard, David K., ed. **Monolithic Refractories** (Detroit: American Concrete Institute, 1982).

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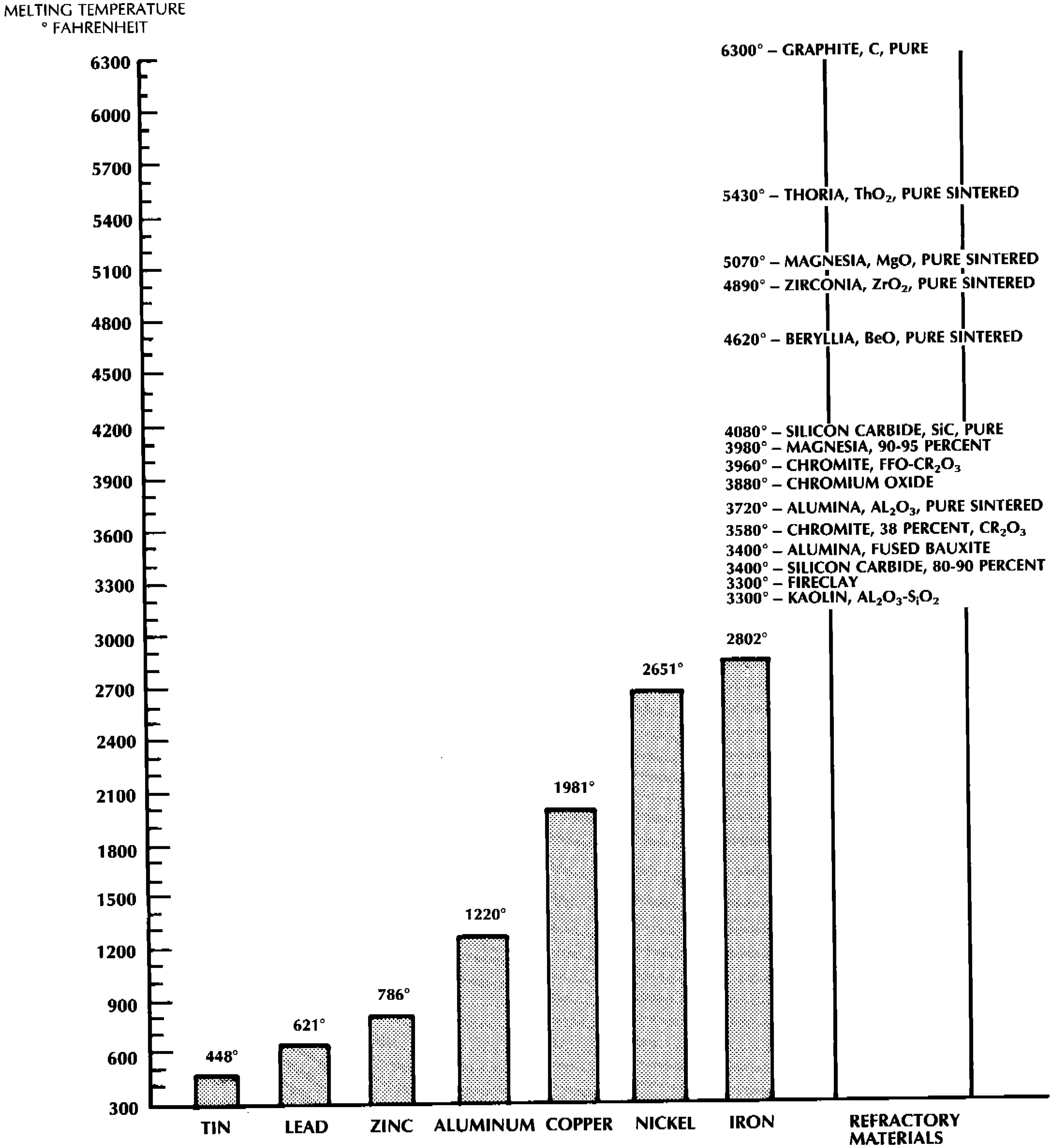
"Refractories," **Current Industrial Reports**, MQ 32C, Annual Summary Reports (Washington: Bureau of the Census, U.S. Department of Commerce).

Rothenberg, G.B. **Current Industrial Reports**, (Park Ridge, New Jersey: Noyes Data Corporation, 1976.), U.S. patents dealing with refractory materials issued 1973 to 1976.

Shaw, Kenneth. **Refractories and Their Uses** (New York: Halstead Press Division, John Wiley and Son, 1972).

"Steel-Plant Refractories," Chapter 2 in Lankford, William T. et al., editors. **The Making, Shaping and Treating of Steel** (New York: United States Steel Company, Tenth Edition, 1985), pp. 37-96.

Appendix 3
Refractory and Industrial Materials Melting Point Chart



KEY INDUSTRIAL MATERIALS

Appendix 4

Colleges and Universities Offering Degrees and Education in Ceramic-Related Fields

Alabama, University of, at Birmingham
School of Materials Engineering
University Station
Birmingham, AL 35294
205-934-8450

Alfred University
School of Engineering/Science
NY State College of Ceramics
Alfred, NY 14802
607-871-2448

Auburn University
Materials Engineering
Auburn University, AL 36849

Brown University
Materials Engineering
Providence, RI 02906

Clemson University
School of Ceramic Engineering
110 Olin Hall
Clemson, SC 29634-0907
803-656-5350

Cornell University
Materials Science Engineering
Ithaca, NY 14853

Drexel University
Materials Engineering
32nd and Chestnut Streets
Philadelphia, PA 19104

Florida, University of
School of Materials/Science/Engineering
Gainesville, FL 32611
904-392-7660

Georgia Institute of Technology
School of Materials Engineering
Atlanta, GA 30332
404-894-2850

Hocking Technical College
School of Ceramic Engineering Technology
Hocking Technical College
Nelsonville, OH 45764
614-753-3591

Illinois, University of, at Urbana-Champaign
School of Ceramic Engineering
105 South Goodwin Avenue
Urbana, IL 61801
217-333-0325

Iowa State University
School of Materials Science/Engineering
110 Engineering Annex
Ames, IA 50011
515-294-0740

Johns Hopkins University
Materials Science and Engineering
Charles & 34th Streets
Baltimore, MD 21218

Massachusetts Institute of Technology
Materials Science and Engineering
77 Massachusetts Avenue
Cambridge, MA 02139

McMaster University
School of Metallurgy/Materials Science
1280 Main Street West
Hamilton, Ontario CANADA L8S 4L7
416-525-9140

Michigan Tech University
School of Metallurgical Engineering
Houghton, MI 49931
906-487-2638

Minnesota, University of
School of Chemical Engineering/Materials Science
151 Amundson Hall
421 Washington Avenue
Minneapolis, MN 55455
612-625-0559

Missouri, University of
School of Ceramic Engineering
Rolla, MO 65401
314-341-4401

North Carolina State University
School of Ceramic/Materials Engineering
229 Riddick Building
Raleigh, NC 27695-7907
919-737-2377

Northwestern University
Materials Science and Engineering
Evanston, IL 60201

Ohio State University
Department of Ceramic Engineering
2041 College Road
Columbus, OH 43210
614-422-2960

Penn State University
School of Ceramic Science/Engineering
201 Steidle Building
University Park, PA 16802
814-865-7961

Pennsylvania, University of
Materials Science and Engineering
34th and Spruce Streets
Philadelphia, PA 19104

Rensselaer Polytechnic Institute
110 Eighth Street
Troy, NY 12180

Rice University
Materials Science
Box 1892
Houston, TX 77251

Rutgers University
School of Ceramics
P.O. Box 909
Piscataway, NJ 08854
201-932-2330

San Jose State University
School of Materials Engineering
127 G. Street
Redwood City, CA 94062
415-364-9402

Toronto, University of
Metallurgy & Materials Science
Toronto, Ontario M5S 1A4
CANADA

Utah, University of
School of Materials Science/Engineering
University of Utah
Salt Lake City, UT 84112
801-581-4941

Virginia Polytechnic Institute & State University
School of Materials Engineering
Virginia Polytechnic Institute
Blacksburg, VA 24061
703-961-6777

Washington, University of
School of Materials Science/Engineering
FB-10
Seattle, WA 98195
206-543-2870

Western Ontario, University of
Engineering Science
London, Ontario N6A 5B9
CANADA

Windsor, University of
Engineering Materials
Windsor, Ontario N9B 3P4
CANADA

Wisconsin, University of, at Milwaukee
Materials Engineering
Milwaukee, WI 53211

Wright State University
School of Materials/Science Engineering
Dayton, OH 45435
513-873-2476

Appendix 5
Refractory Testing Laboratories
These facilities provide various testing services for those companies that need data or analysis of refractory products

Ambrick Testing
3600 Crawford
Philadelphia, PA 19129

Bricmont & Associates
395 Valleybrook Rd.
McMurray, PA 15317

Coors
600 9th St.
Golden, CO 80401

Corning Engineering Labs
HP-ME-02-E6
Corning, NY 14831

Crucible Research Center
P.O. Box 88
Parkway West & Route 60
Pittsburgh, PA 15230

Dynatech
99 Erie Street
Cambridge, MA 02139

Emhart Industries
Box 700
Windsor, CT 06095

Harrop Industries
3470 E. Fifth Avenue
Columbus, OH 43219

Herron Testing Labs
5405 E. Schaff Rd.
Cleveland, OH 44131

Hocking Technical College
Route 1
Nelsonville, OH 45764

Mineral Resources Institute
University of Alabama
Drawer A-Y
Tuscaloosa, AL 35486

Orton Ceramic Foundation
6991 Old 3C Hwy.
Box 460
Westerville, OH 43081

Owens-Illinois
One Seagate
Toledo, OH 43666

Pittsburgh Testing Lab
850 Poplar Street
Pittsburgh, PA 15220

Porous Materials
Cornell Industrial Research Park
Building 4
Ithaca, NY 14850

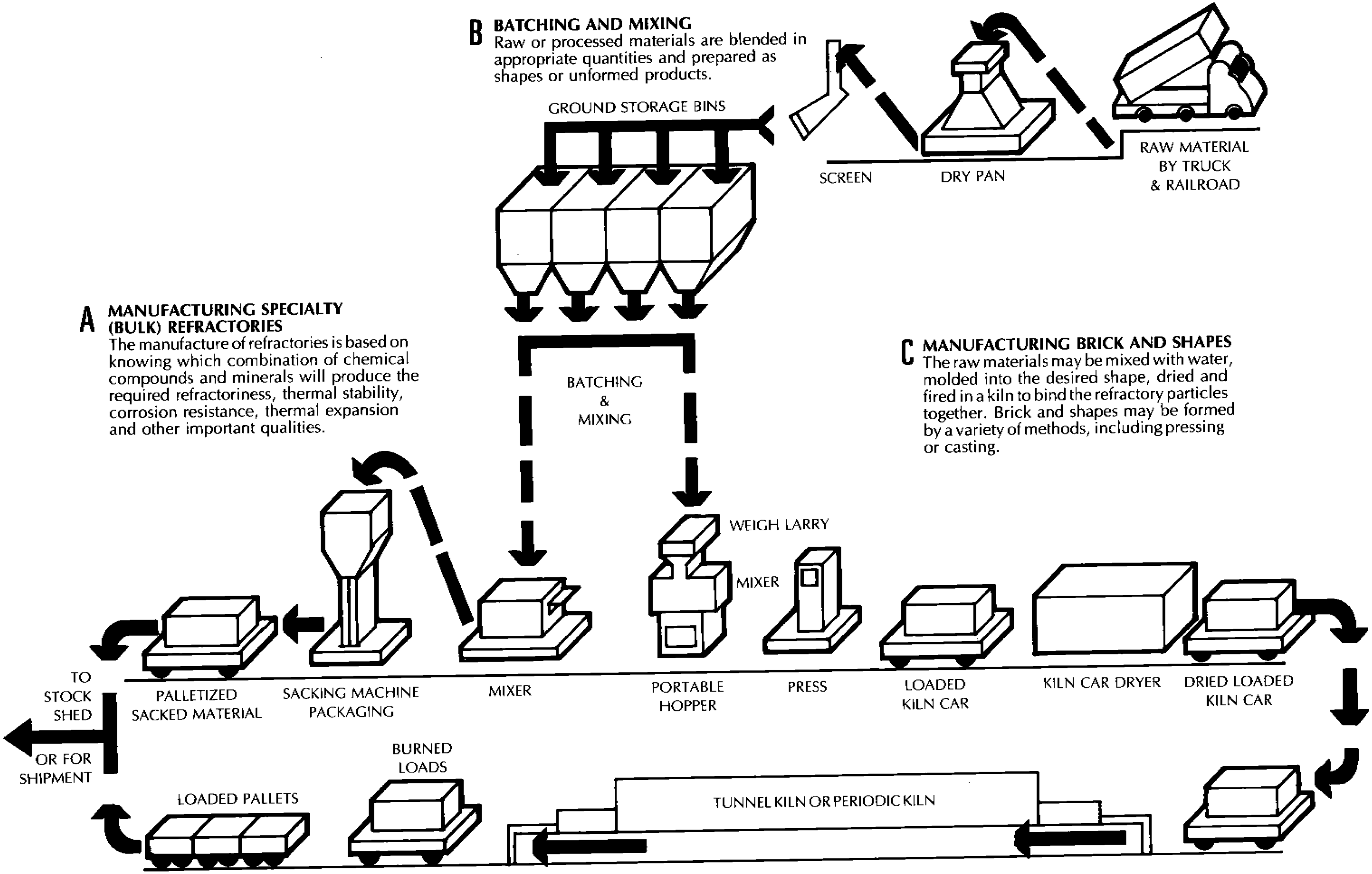
Purdue University
Dept. of Materials Eng.
Lafayette, IN 47907

Refractories Research Center
Ohio State University
2041 College Road
Columbus, OH 43210-1178

Refractory Service, Inc.
950 Gemini
Houston, TX 77058

Robert Jenkins
906 Medical Center Blvd.
Webster, TX 77598

Spectro Chemical Labs
8350 Frankstown Ave.
Pittsburgh, PA 15221



Appendix 6

Typical Refractory Manufacturing Flow Sheet

GLOSSARY

Advanced Ceramics	Produced with tightly controlled chemical compositions through special processing. They exhibit superior properties and reliability and often perform in severe environments and emerging applications.
Aggregate	Composed of mineral fragments.
Alkalies	Any of various bases like hydroxides of sodium, potassium and lithium which neutralize acids.
Alumina	An oxide of aluminum.
Anchor	A ceramic or metal fitting designed to hold refractories in place.
Andalusite	A mineral consisting of alumina and silica.
Arc Furnace	An enclosed place in which heat is produced by an arc formed between two electrodes.
Bauxite	A rock consisting of hydrous aluminum oxide with various impurities; the principal ore of aluminum, and raw material for mullite and high-alumina refractories.
Binder	A substance added to a granular material to give it workability and green or dry strength.
Blister Copper	A partially refined form of copper, having a blistered surface after smelting due to the gases generated during solidification.
BOF	Basic Oxygen Furnace (for steelmaking).
BOP	Basic Oxygen Process (for steelmaking).
Bosh	The section of a blast furnace beneath the hearth and the stack, where iron ore is reduced to iron metal.
Bustle Pipe	Large refractory lined pipe which encircles a blast furnace and supplies hot air (blast).
Calcine, calcines	Refractory material, often fire clay, that has been heated to eliminate volatile constituents and to produce desired physical changes.
Calcined Bauxite	Bauxite fired to high temperatures.
Campaign	A life of anything.
Carbon-Ceramic refractory	A manufactured refractory comprised of carbon (including graphite) and one or more ceramic materials such as fireclay and silicon carbide.
Carbon refractory	A manufactured refractory comprised substantially or entirely of carbon (including graphite).
Carbon refractory petroleum-coke-base	A manufactured refractory comprised substantially of calcined petroleum coke.
Castable	A combination of refractory grain and suitable bonding agent that, after the addition of a proper liquid, is generally poured into place to form a refractory shape or structure which becomes rigid because of chemical action.

Catalyst — A substance, which, by its presence alters the rate of reaction and itself remains unchanged at the end of the reaction.

Ceramic — A broad term for products such as pottery and bricks from heat-resistant nonmetallic, inorganic materials such as clay, bauxite, alumina, silica, magnesia, silicon carbide and the like.

Charging — Insertion of a load of material into a furnace.

Checkerwork — An arrangement of preformed refractory shapes in which waste heat is stored and recovered.

Chromite — A mineral containing oxides of chromium, iron, aluminum, and magnesium.

Clinker — A mass of incombustible matter fused together, as in the production of cement or the burning of coal.

Coke — The solid product resulting from the incomplete combustion of coal, consisting principally of carbon; used chiefly as a fuel in metallurgy to reduce metallic oxides to metal.

Crown — A furnace roof, especially one which is arched.

Crucible — A ceramic pot or receptacle made of materials such as graphite or silicon carbide, with relatively high thermal conductivity, bonded with clay or carbon and used in melting metals.

Cupola — A vertical furnace for melting iron.

Cyclone — A device for removing small or powdered solids from air, water, or other gases or liquids by centrifugal force.

Dead-Burned — The state of a basic refractory material resulting from a heat treatment that yields a product resistant to atmospheric hydration or recombination with carbon dioxide.

Diaspore — A mineral, aluminum hydroxide.

Diaspore Clay — A rock consisting essentially of diaspore bonded by fire clay.

Direct Bonded Basic Brick — A fired refractory in which the grains are joined predominately by a solid state diffusion mechanism. The term "direct bond" was initially applied to fired magnesite-chrome refractories.

Dolomite, raw refractory — Natural limestone consisting predominantly of magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$) in approximately equal ratio and which is suitable for use as a refractory material.

Eutectic — The mixture of two or more components whose melting point is lower than those of any individual component.

Extruded — The forming of materials such as clay to a desired cross section by forcing it through a die.

Fettling — The protection of the hearth or original lining of a furnace with loose granular refractory material.

Firebrick, insulating — A refractory brick characterized by low thermal conductivity and low heat capacity.

Fireclay — An earthy or stony mineral aggregate which has the essential constituent hydrous silicates of aluminum with or without free silica; plastic when sufficiently pulverized and wetted; rigid when subsequently dried; and of suitable refractoriness for use in commercial refractory products.

Foundry	A place where metal is cast into shapes.
Flue	Any duct or passage for air or gas in a furnace.
Fused or fusion cast refractory	A solidified material made by melting refractory ingredients and pouring it into molds (see also molten cast refractory).
Graphite	A pure carbon mineral in tabular crystals of hexagonal outline with prominent basal plane.
Heat, a	One batch of steel.
Induction Furnace	An enclosed place in which heat is produced by an electromotive force.
Kiln	A furnace for the calcination or firing of ceramic materials, including refractories.
Kiln Furniture	Embraces all those products used to support, hold or position ceramic articles in highly heated kilns during the baking or firing process, including biscuit, glost and enamel firings. Different types of kiln furniture include spurs, stilts, thimbles, pin crank systems and pins (including sagger pins), batts, cross bar systems with beams, foot support systems with setters, box type plate setters, tile boxes and cassettes, and tile cranks.
LPG	Liquified Petroleum Gas.
Magnesia	Magnesium oxide.
Magnesite	A mineral consisting essentially of magnesium carbonate.
Magnesite, grain	Dead-burned magnesia in granular form of size suitable for refractory purposes.
Molten cast refractory	A solidified material made by melting refractory ingredients and pouring into molds (see also fused or fusion cast refractory).
Monolithic refractory	A refractory which may be installed *in situ*, without joints to form an integral structure.
Mortar, refractory	A finely ground preparation which becomes plastic and trowelable when tempered with water, and is suitable for laying and bonding refractory brick.
Mullite, Synthetic	A material made by heating a mixture of alumina and silica or clay to a high temperature, having a composition of $3AL_2O_3{\cdot}2SiO_2$.
Nozzle refractory	A refractory shape containing an orifice for the purpose of transmitting molten metal from a refractory-lined container.
Oxide	A binary combination of oxygen with an element or radical.
Paver Blocks	A refractory brick shape used to form the bottom working lining of furnaces or abrasion resistant floors.
Periclase Grain	A crystalline magnesium oxide in granular form; this contains at least 85% magnesia.
Perlite	A volcanic glass which expands on heating and forms a useful insulating aggregate.
Plastic refractory	A refractory material, tempered with water, that can be extruded and that has suitable workability to be pounded into place to form a monolithic structure.
Pouring Pit refractory	A refractory associated with the transfer or flow control of molten steel between furnace and mold.

Pyrometric Cone Equivalent (PCE)	The number of that Standard Pyrometric Cone whose tip would touch the supporting plaque simultaneously with a cone of the refractory material being investigated when tested in accordance with ASTM Test Method C24, Test Method for Pyrometric Cone Equivalent (PCE) of Refractory Materials.
Ramming Mix	A refractory material, usually tempered with water, that cannot be extruded but that has suitable properties to permit ramming into place to form a monolithic structure.
Reduce (Reduction)	To deoxidize or convert oxidized ores to metals.
Refractories	Nonmetallic materials having the ability to retain their physical shape and chemical identity when subjected to high temperatures above 1000°F (or 538°C).
Refractories, acid	Refractories containing a substantial amount of silica that may react chemically with basic refractories, basic slags, or basic fluxes at high temperatures.
Refractories, basic	Refractories whose major constituent is lime, magnesia, or both, and which may react chemically with acid refractories, acid slags, or acid fluxes at high temperatures.
Refractoriness	In refractories, the capability of maintaining a desired degree of chemical and physical identity at high temperatures and in the environment and conditions of use.
Refractory fibers	Nonmetallic, inorganic continuous, or non-continuous filaments having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 1000°F (538°C).
Refractory Magnesia	A dead-burned refractory material consisting predominantly of crystalline magnesium oxide.
Regenerator	A chamber filled with checkerwork through which incoming combustion air and hot exhaust gases pass alternately so that the heat from the gases is stored in the checkerwork and given off to the air.
Reverberatory	A furnace or kiln in which the flame passes over the charge to be heated.
Schists	Crystalline rocks whose constituent materials are arranged in layers which are easily separated.
Silica	The oxide of silicon, the major chemical constituent of sand.
Siliceous	A material containing silica.
Silicon Carbide	A hard compound of silicon and carbon used as an abrasive or refractory grain or electrical resistor.
Sillimanite	A mineral, consisting of alumina and silica.
Sintering	The agglomeration of particles by heating; the material need not be completely melted.
Skew Block	A sloping, shaped block against which the end of an arch rests.
Slag	Melted matter separated during the reduction of a metal from its ore.
Slip	A suspension of creamy consistency used for casting.

Smelting	Thermal processing wherein chemical reactions take place to produce liquid metal from an ore.
Soda	Sodium carbonate or sodium oxide sometimes called soda ash; a major constituent in glass.
Spalling of refractories	The cracking or rupturing of a refractory unit, which usually results in the detachment of a portion of the unit.
Spalling of refractories, thermal	The spalling of a refractory unit, which usually results in the detachment of a portion of the unit produced by a difference in temperature.
Stills	An apparatus consisting of a vessel in which a liquid is heated and vaporized and a cooling device for condensing the vapor.
Stoker	A mechanical device for feeding coal or other solid fuels to a furnace.
Thermal Conductivity	A measure of the capacity of a material to conduct heat.
Tuyere	An opening through which the blast of air enters a blast furnace, cupola or forge to facilitate combustion.
Vermiculite	Minerals similar to mica which expand greatly when heated; used in the expanded state for heat insulation.
Vitrification	Changing or making into glass or a similar substance, especially through heat fusion.
Zircon	A mineral, zirconium silicate; used as a refractory.
Zirconia	A zirconium oxide used as pigments for paints and in the manufacture of refractories.
Zirconium Oxide refractory	Refractory products consisting substantially of zirconium dioxide.

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