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OPPORTUNITIES IN THE PRODUCTION OF SECONDARY NON-FERROUS METALS [1]

by

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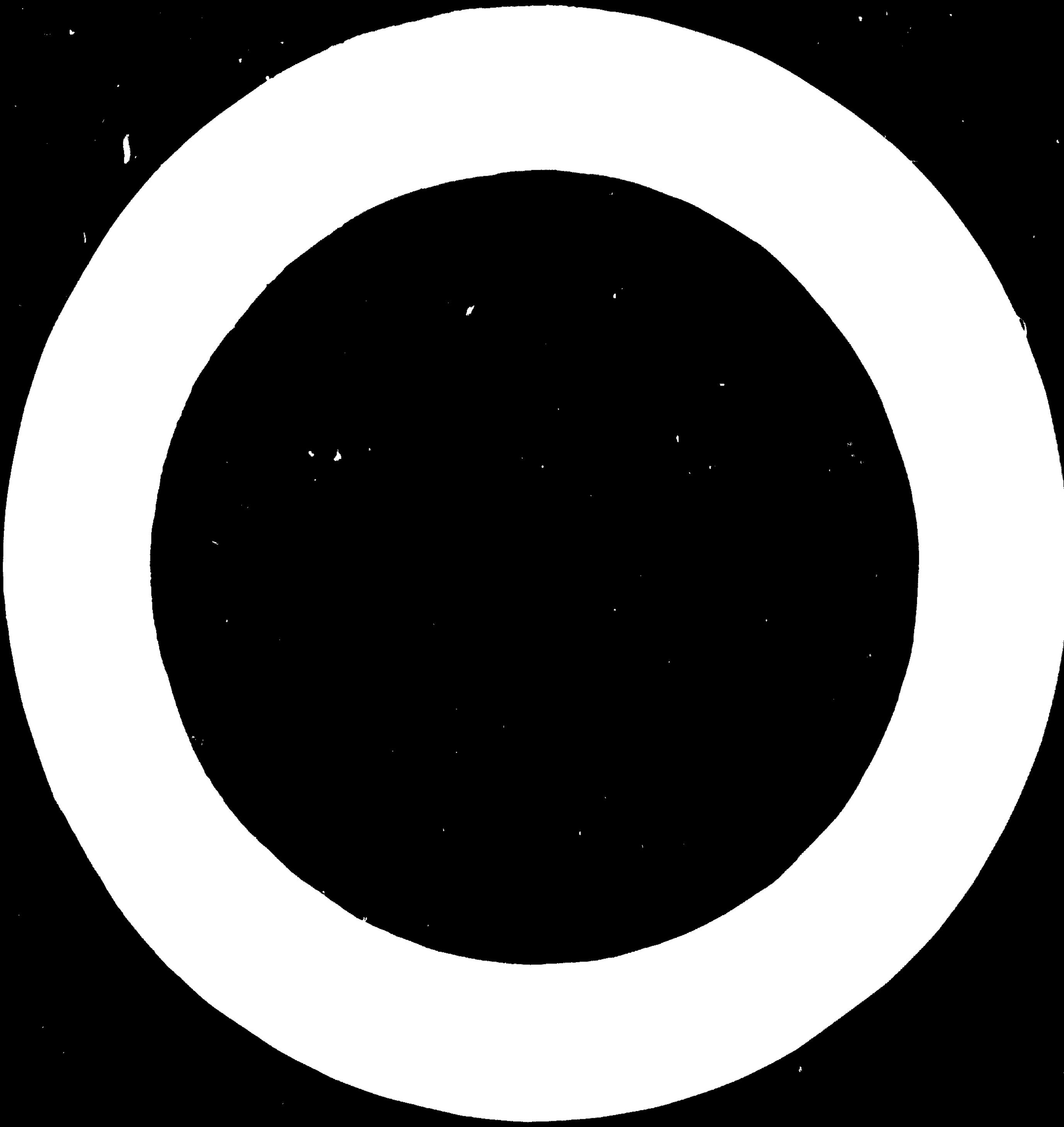
c. Operate continuously for a specified period to demonstrate plant capacity, efficiency, and quality of product.

d. Expand demonstration plant to full industrial scale.

e. Repeat above procedures for each additional plant.

The task of setting all of the above actions into motion according to a well-coordinated plan will be difficult and frustrating. It will require the combined efforts of many people, but the reward could be enormous.



ABSTRACT

Recently discarded, durable metal goods manufactured some 10 to 50 years ago comprise a substantial part of the raw materials currently processed by secondary smelters. Opportunities in the current industry must, therefore, be found in processing these old materials as well as the new scrap being generated by manufacturing plants. Since the scrap materials of tomorrow are being manufactured as durable goods today, we are afforded an opportunity to examine them for potential future benefits. It is shown that these metal materials are accumulating as goods-in-use in the United States and collectively reaching enormous proportions. They comprise a growing metal resource. Documented data on the actual quantity of scrap materials processed annually show that they supply a large part of the total metals consumed. The record also shows that primary and secondary metal production rise and fall approximately in unison, and for some commodities the fraction of metal supplied from scrap appears to be increasing slightly more rapidly than primary metal production. Such data may be useful for estimating the profitable scale of operations in a developing country simply by comparing their level of industrialisation with comparable reliable data published by other countries. The

ratio of profitable secondary metals production for two countries should be approximately proportional to the ratio of their levels of industrialisation. Such a comparison of data would simply indicate the total volume potential, but the economic potential could then be estimated in accordance with domestic capabilities and other assets. Accordingly, opportunities in the production of secondary metals would be found through several means, such as shrewd and clever management, adopting only the most advanced and efficient technology, and possibly negotiating suitable trade agreements with other countries. Several typical examples of interesting possibilities are discussed, including distillation, electrometallurgy, mechanical separations, and chemical processes.

INTRODUCTION

A significant part of the metals consumed to meet the demands of societies is reclaimed from the discarded durable goods manufactured some 10 to 50 years ago. It follows that the metals contained in recoverable metallic goods now in use will be reclaimed some day in the future to help supply a large part of tomorrow's even greater demands. It is logical to look into the reservoir of metal goods now in use for new opportunities in the production of secondary metals.

Appropriately, international attention has been directed to the exchange of information on secondary metals science and technology because these materials appear to be destined for greater national and international importance as a significant element of domestic and foreign commerce. There has been previous exchange of information, but the importance of planned exchange discussions concerning both the broad and in-depth aspects of the subject should be stressed.

There is little information which contains conclusive evidence that the more industrialized countries have traditionally contributed much of their technical knowledge to less industrialized countries during their initial period of industrial development. Experience has shown that much less time is required if newcomer producers adopt and apply the latest available technology rather than spend the time and money to develop the equivalent advantage independently. The transfer of such beneficial information is, in effect, an objective of the UNIDO meeting on secondary metals. Countries about to enter more heavily into the recycling industry may have, as a result of such meetings, a preliminary opportunity to evaluate and adopt the most attractive secondary metals processes without having to sacrifice prior investments. Perhaps the best way to communicate information of this nature to an international audience is to describe some of the salient features of the secondary metals industries in the countries of the participants. Since new opportunities are directly related to the size and nature of the resource, following preliminary discussions will attempt to characterize the scrap resourc which corresponds to the United States' level of industrialization. They concern the principal nonferrous secondary metals industries in the United States--aluminum, copper, lead, and zinc.

Recycling materials of commerce becomes more critically important with the increasing affluence that normally accompanies extensive industrialization. This is an ironic but inevitable situation that occurs when a growing population becomes accustomed to more and more materials per capita at a time when national mineral resources are being depleted at ever-increasing rates. The consequence of this situation is a concerted effort to extend primary and secondary processing capabilities in order to accommodate leaner and leaner grades of domestic ores and greater quantities of metal scrap and waste materials. An obvious alternative is to increase imports of ores, scrap, bulk metal, and finished goods. Such a situation prevails in the United States, where, for example, the average grade of copper ore mined has decreased from about 0.95 percent copper to about 0.7 percent during the past 20 years. The average grade of iron ore mined in the same period has dropped from near 55 percent iron to slightly over 40 percent. There has been concurrent increase in the consumption of secondary copper and iron.

Value of Secondary Metals

The market value of any particular secondary metal is influenced significantly by its quality with respect to specifications. The rigidity of specifications adopted may differ markedly from country to country, but the specification limits will normally become more rigid with advancing industrial development. Ordinarily there is a concurrent improvement in the quality of secondary metal products. In the United States, for example, the historical inference that secondary metals were not virgin and therefore not pure is vanishing.

Early in the first half of this century, secondary metal processes were primarily simple melting operations in which a wide variety of scrap metal constituents were blended together with little or no refining accomplished in the process. As such, the metal products were not considered as useful, for any purpose, as primary or virgin metal. However, shortages arising in World War I led to a general acceptance of secondary metals, thus stimulating a rapid growth of the industry. During this period, better procedures were developed to produce more acceptable secondary products. A similar situation arose during World War II. Simultaneously, the primary metal producers developed a greater capacity for scrap metal and metal-bearing wastes and the U. S. secondary metals industry evolved into the pattern that exists today.

Although individual metals may be reprocessed many times in alloyed form (such as bronze and brass) but never selectively extracted and refined to high individual purity, they are, for the purpose intended, equivalent in every way to primary metals that could be used in their place. Furthermore, large and growing quantities of scrap are now processed in primary smelting operations, and that part of the smelter product which is derived from scrap metals is undistinguishable from the companion metals derived from ore.

The importance of nonferrous secondary metals in the United States is reflected in Table 1 which shows their worth determined at the May 7, 1969 market prices. The value of recovered copper alone exceeds one billion dollars. The annual recovery of mercury is worth 12 million dollars and the lead is worth more than 160 million. It is thus obvious that the production of secondary metals is profitable in the United States. It is also evident that the scrap resource and the marketability of secondary metal products should be examined carefully before venturing into this competitive business.

Table 1 - United States Secondary Metal Consumption*

1967

Metal	Quantity	Units	1969 Value[1/] Million Dollars
Copper	1,243,000	Short Tons	1,096[2/]
Aluminum	885,000	" "	403
Lead	554,000	" "	161
Zinc	263,000	" "	76
Antimony	25,568	" "	26
Tin	22,790	" "	71
Mercury	22,150	Flasks	12
Silver	59,000,000	Ounces	101
Gold	2,000,000	"	70

* Bureau of Mines Office of Mineral Resource Evaluation.

[1/] Prices, American Metal Market, May 7, 1969

[2/] $853,000,000 less than the value of secondary iron.

In-Use Accumulations

Table 2 shows the accumulated quantities of copper, lead, and zinc as typical examples of the growth of metals in the in-use reservoir. By 1968 these accumulations had reached the tremendous proportions of 40.3 million tons of copper, 4.0 million tons of lead, and nearly 4.5 million tons of zinc.

Table 2 - Estimated Accumulation of Copper, Lead, and Zinc in Use in the United States, 1940-1968* (1,000 short tons)

Year	Copper[1]	Lead[2]	Zinc[2]
1940	14,735	180	264
1945	19,933	873	1,173
1950	24,169	1,674	1,722
1955	28,615	2,490	2,525
1960	32,630	3,052	3,085
1965	37,346	3,587	3,928
1968	40,333	4,030	4,473

* Bureau of Mines Office of Mineral Resource Evaluation
1/ 1907 base of reference
2/ 1939 base of reference

These large accumulations of metals will, no doubt, continue to grow during the next decade, but the possibility of a marked change in the trend within the next 50 years is not inconceivable. Although the above trends are currently typical in the United States, it is highly possible that the store of recoverable metals now in use in various other countries may represent the only domestic supply. In such cases it becomes particularly important to develop complete and accurate resource data in order to assure prudent ucilization. Opportunities can best be determined from reliable information on the magnitude, location, composition of the metal goods in use, and a firm knowledge of the portion of in-use materials likely to become available for recovery in the near future. It is equally important to obtain timely economic and technological information pertaining to salvaging, reprocessing, and marketing. Such determinations usually evolve spontaneously as a matter of competition in a market system.

Overview of Major Secondary Metals in the United States

In the foregoing discussions we have examined the relative significance of the secondary metals segment of the total metals industry. However, a more specific characterization of the secondary metals industry is best illustrated by a graphic representation of a typical materials flow diagram. Figure 1 is such a representation designed to show the sequential movement of primary and secondary metals from source materials through production, in-use, salvage and recycling phases. Since the time periods required for materials to pass through the various sections differ widely, and the average time of residence in the in-use segment may exceed several decades, a precise accounting of the quantity of metal in each of the flow channels is virtually impossible. Accordingly, the respective dimensions of the various channels in the flow diagram have no quantitative significance.

Materials entering the production side of the diagram include domestic and foreign ores and scrap. The metal consumers are supplied by primary and secondary metal producers and foreign imports. Process losses occur in both primary and secondary production plants, and the total domestic consumption of metal is equal to the total metal content of raw materials input to the metal producers, less processing losses

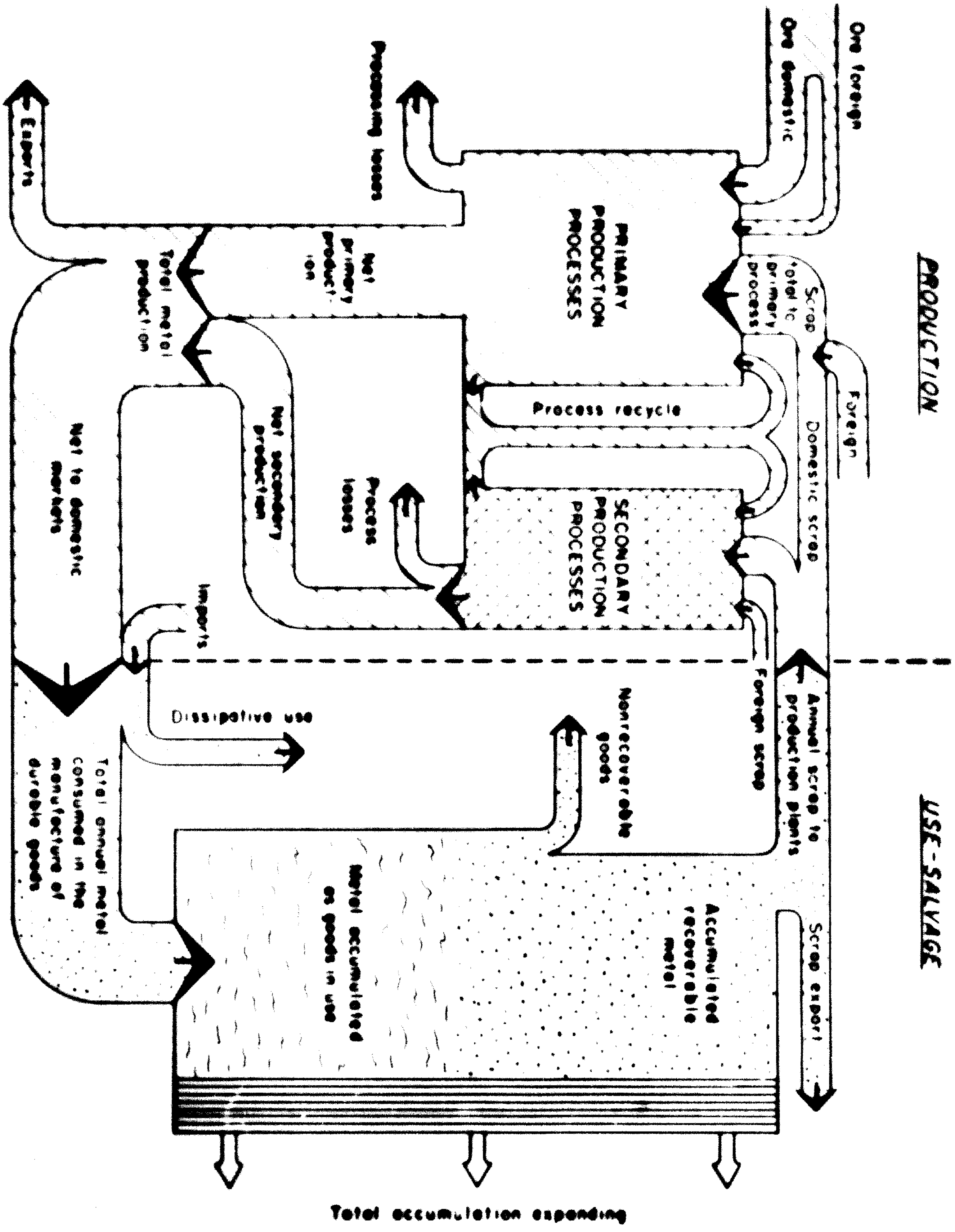
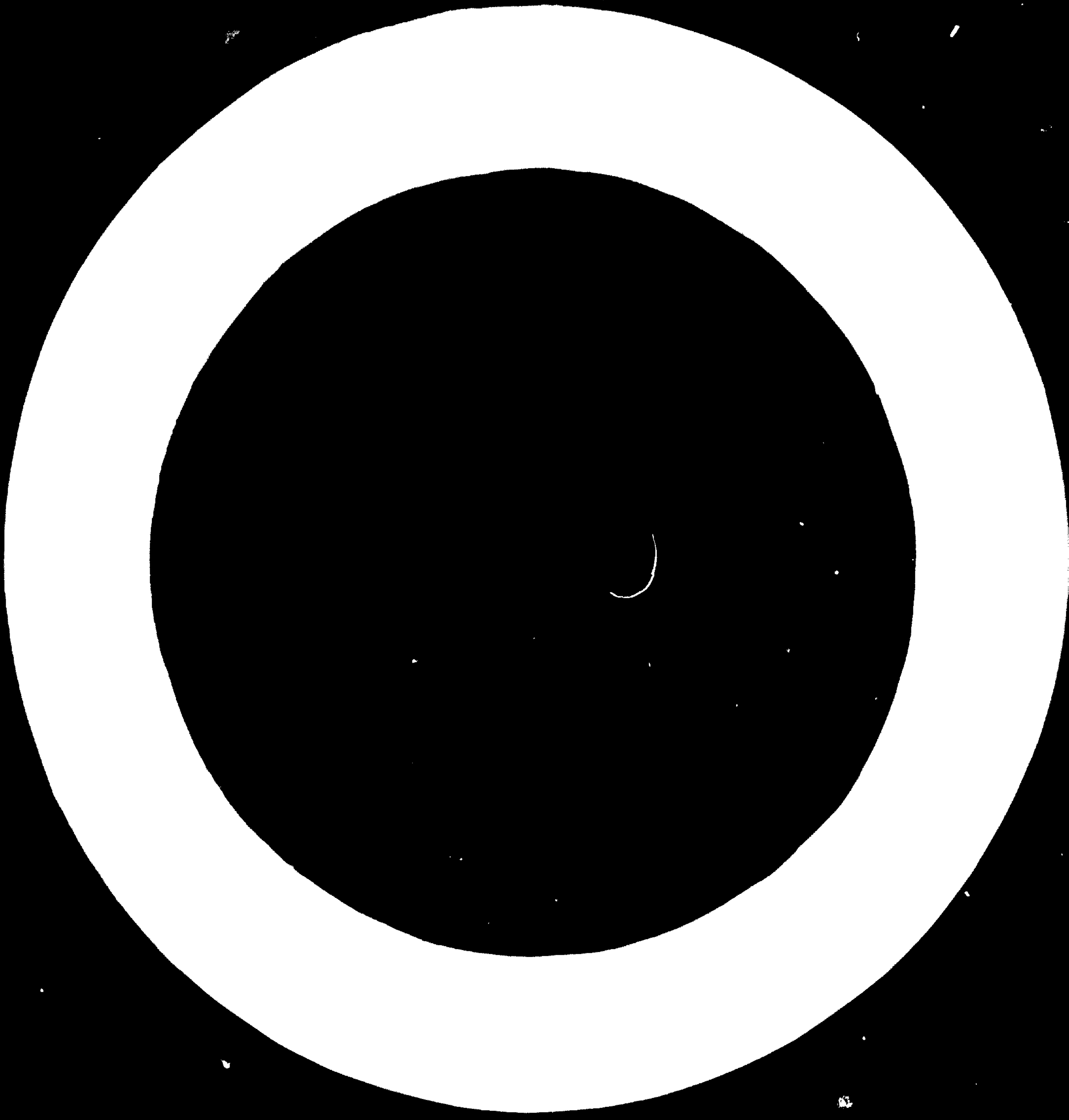


Figure 1 - Metal Production, Use, and Salvage Cycle



and exports. It will be observed that the primary and secondary components of the diagram are parallel operations. However, scrap is consumed as a part of the raw materials flowing to the primary metal producers, but no significant amount of ore is processed in secondary metal operations.

The diagram shows that domestic metal consumption comprises the total materials input to the use and salvage side of the cycle. Losses from this section of the cycle include those metals used in nonrecoverable ways, scrap lost or not worth collecting, and exported metal goods and scrap. Statistical data for several of the major U.S. secondary metals show that the total amount of metals permanently lost in nonrecoverable materials is significantly less than the total amount used in recoverable materials. If the total amount of recycled scrap plus exported scrap, and nonrecoverable processing loss is less than the corresponding total annual consumption, then the total metal in use and that which is available in recoverable scrap comprises a source of metal supply that increases. The materials flowing out of this system include exports, dissipative uses, nonrecoverable scrap, and scrap returned to primary and secondary metal producers. These materials are the secondary metals resource.

Most of the metallic items now entering recycle channels as scrap were newly manufactured 10 to 50 years ago. The similarity of these materials and current manufactured metallic goods is determined primarily by the social and technological changes that have occurred during the intervening period. For example, many years ago beer was sold in jugs and buckets. Later it was sold in bottles and tin plated iron cans. Now much of it is sold in bottles and aluminum cans and small aluminum barrels. We might expect that tomorrow it could be sold in paper or plastic packages. If it continues to be sold in metal containers, it is logical to assume that many of the containers will be recycled as secondary metal. Such trends affect corresponding changes in the scrap processing technology. Since there is normally a significant lapse of time between the introduction of a new metal article and its appearance as scrap metal, there is an opportunity to predict, with reasonable accuracy, future needs in new salvage and processing technology. In the above case, increased use of aluminum cans could represent a significant input to secondary aluminum smelters. If plastic replaces aluminum cans for example, the processors must turn to other materials.

The importance of secondary metals in the channels of commerce is illustrated in figure 2. The contribution of major U. S. secondary metals producers toward the total annual needs for aluminum, copper, lead, and zinc are shown for the years 1959-1967[1]. Except for a drop in 1967, the total consumption has increased steadily over a 10-year period, and the portion supplied from secondary metals has increased substantially in unison with primary metal production. In order to accurately follow secondary metal use patterns, it is necessary to account for the total supply-demand relationships and the use of both primary and secondary metals.

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[1] Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

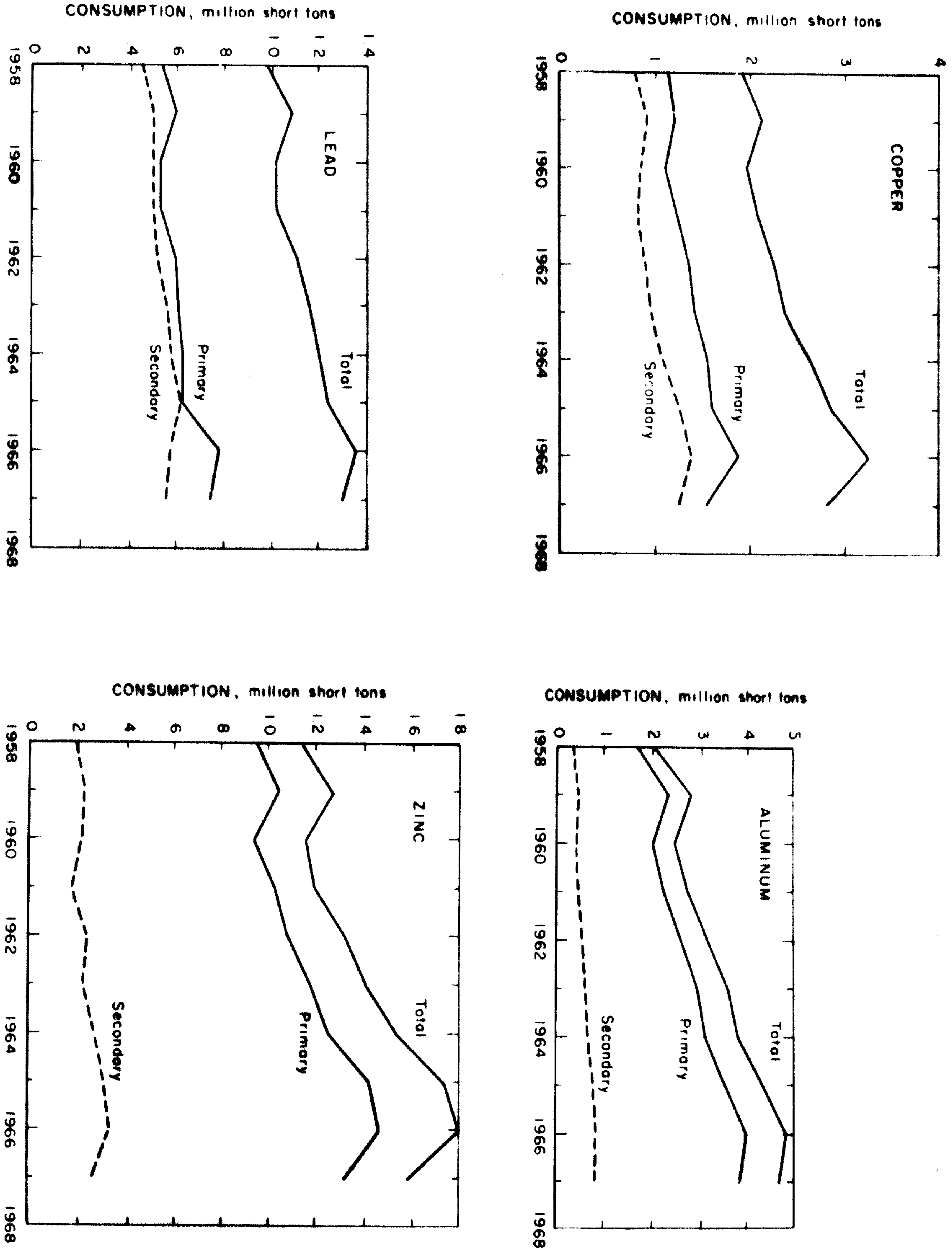
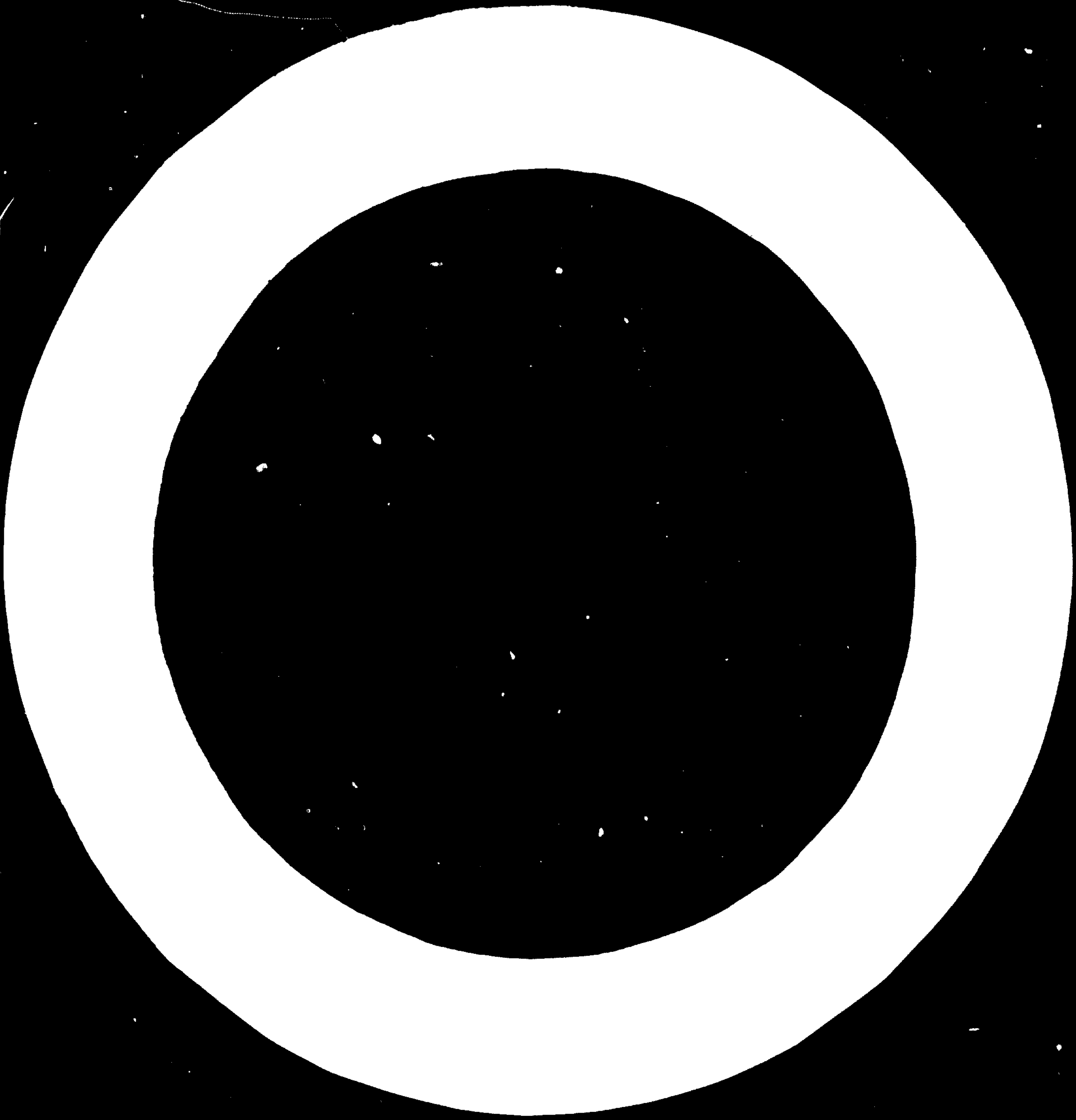


Figure 2 – United States Consumption of Primary and Secondary Aluminium, Copper, Lead and Zinc, 1958–1967



The growth of any metal processing industry is determined primarily by two factors; the availability of raw materials and the marketability of the product. It is normal, therefore, in the secondary metals industry for the growth pattern to follow trends in the availability of scrap. In logical sequence, significant amounts of new types of scrap and other metal-containing waste products will first appear in the fabricating plants as new scrap. Much later it will reappear as old scrap comprised of discarded consumer goods. Finally, these materials will move through the brokers and into the secondary smelters or foundries. The collective quantity of materials in all phases of the use-discard cycle determines the size of the salvage and refining industry that can prosper on this resource.

It is relatively simple for a country to account for the physical properties and rate of depletion of its domestic natural mineral resources because their compositions and rates of consumption are substantially constant over long periods. In contrast, the source of raw materials for secondary metal producers often fluctuates drastically in short cycles, and the variety and availability of scrap raw materials often changes abruptly and unpredictably. For these reasons the variations in primary smelter raw materials are not likely to be as drastic as they are in secondary smelters where the supply, the quality, and the price of scrap can change daily. Since other papers will relate specifically to the details of various processes and resulting secondary products, the following is a general comparison of industry characteristics.

Secondary Aluminum

The United States production of primary aluminum increased 2.3 times in the period 1958 through 1967. The production of secondary aluminum increased 2.1 times in the same period and secondary aluminum producers are now well established in the United States and steadily growing in total capacity. The types of materials being recovered and reprocessed are well documented by the National Association of Secondary Materials Industries in their circular NF 66 (2) which lists 21 different scrap classification types. A recent review (3) of dealer operations and consumer use of aluminum scrap describes the salient features of the industry. It is noted that secondary smelter operators have about 75 percent of total costs invested in raw materials which must be purchased on a competitive market. Accordingly, the most practicable materials to process in a secondary plant are those which are most nearly like the intended product and thus require minimum processing. These types are usually in the form of common aluminum-base alloys. In 1967, 697,751 short tons of secondary aluminum (1) were recovered from new and old scrap as follows:

	(Short Tons)
New Scrap	
aluminum-base	568,782
copper-base	81
zinc-base	71
magnesium-base	313
Old Scrap	
aluminum-base	127,681
copper-base	70
zinc-base	569
magnesium-base	186
Total	697,751

Aluminum alloys comprised about 90 percent of the total secondary aluminum recovered in 1967, and aluminum recovered as metal comprised only 8 percent. All other forms of recovery are relatively insignificant as shown in the following list:

Form of Recovery	Short Tons
as metal	53,656
aluminum alloys	628,848
in brass and bronze	643
in zinc-base alloys	8,304
in magnesium-base alloys	1,195
in chemical compounds	5,105
	697,751

Obviously, it is not practicable to convert all scrap materials back to the original composition. Some smelters process widely different grades of raw materials, usually in different equipment and by different processes. A diagram of typical operations and materials flow is shown in figure 3.

Problems in the secondary aluminum plant are very similar to those in any other secondary metals plant. Identification and segregation of scrap into categories appropriate for making various products is still problematic, and the need for improved scrapyard segregation procedures persists. Melting and blending procedures have been fairly well optimized in this industry and refining is relatively simple. Since excessive amounts of chlorine gas are needed to remove impurities other than magnesium from molten aluminum, the normal practice involves careful segregation of charge materials; chlorine removal of magnesium; and dilution of copper, iron, and other impurities with high grade scrap or

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OPPORTUNITIES IN THE PRODUCTION OF SECONDARY NON-FERROUS METALS

Addendum 1:

Policies, Incentives and Programs [1]

by

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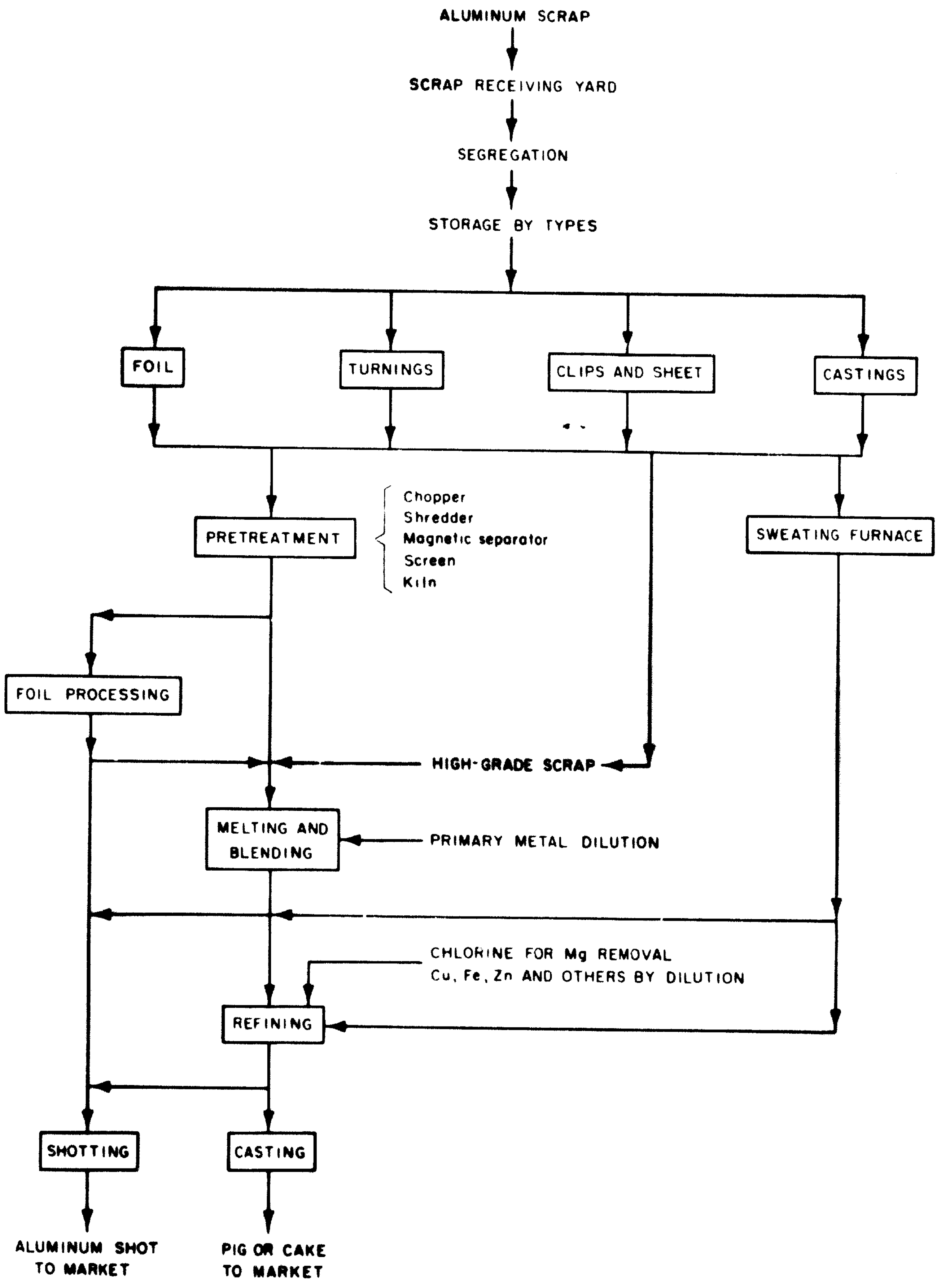


Figure 3 - Secondary Aluminum Processing

primary metal. The removal of large quantities of copper and zinc from aluminum persists as a problem. Paper-backed aluminum foil scrap is another problem which only a few plants are equipped to handle.

Secondary Copper

A comparison of current practice in the production of secondary copper with production methods described in 1961 (4), reveals a fairly stable technology during the last 8 years. Processing methods and problems are not unlike those in secondary aluminum except perhaps in the greater variety of scrap materials, processing procedures, and the total production which is about 30 percent greater than secondary aluminum production. The production of secondary copper increased more than 1.5 times from 1958 through 1967 while primary copper production increased about 1.4 times. By 1967, the amount of United States copper consumption supplied from secondary sources had reached more than 44.5 percent.

The standard scrap classification circular (2) lists 38 different types of copper scrap most of which comprise various items of the many brass and bronze compositions. Most of the secondary copper recovered from scrap processed in the United States in 1967 (1) was in copper-base alloys contained in new and old scrap as follows:

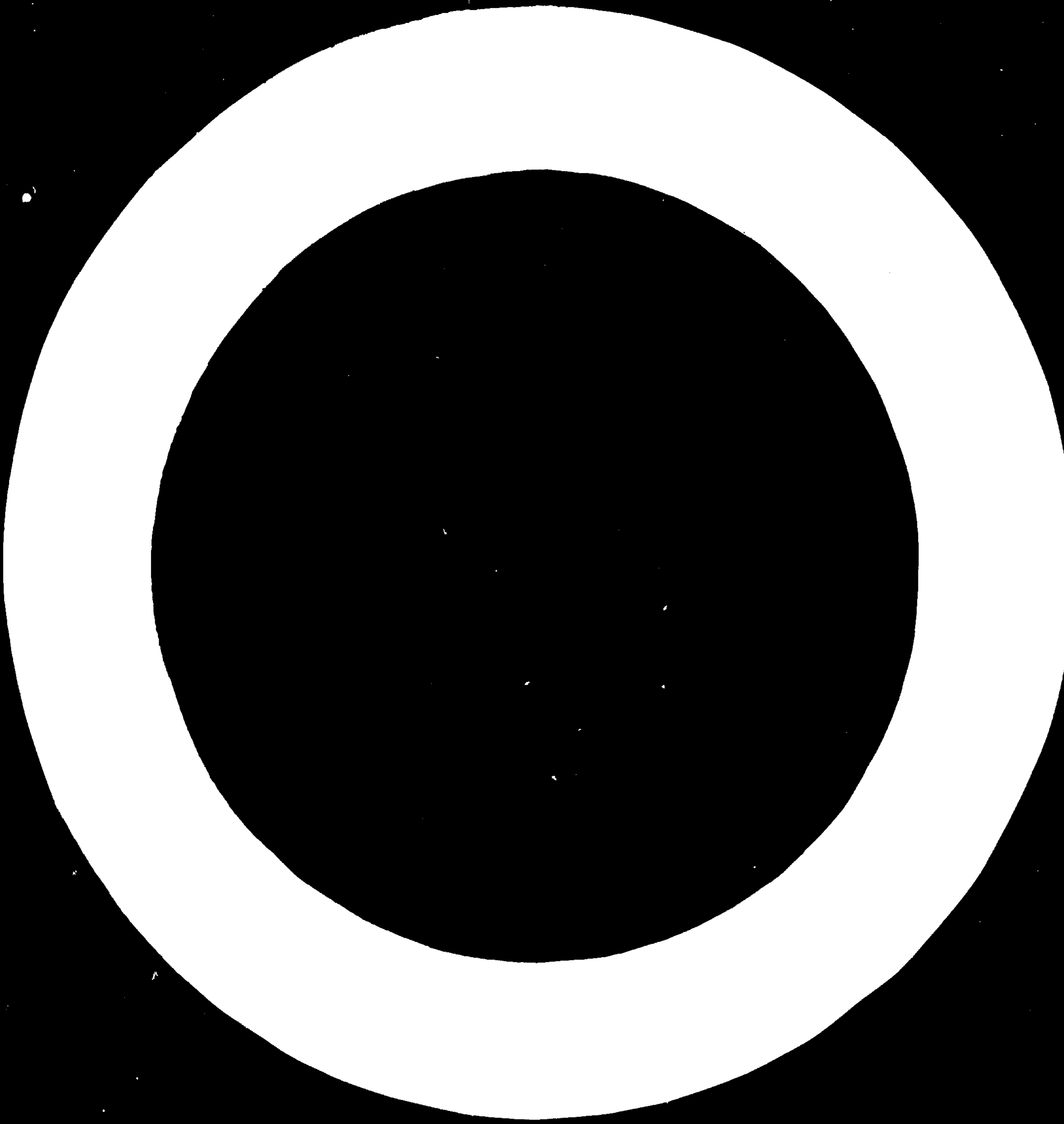
New Scrap	Short Tons
copper-base	667,000
aluminum-base	10,000
nickel-base	157
zinc-base	11

Old Scrap	Short Tons
copper-base	476,471
aluminum-base	5,500
nickel-base	623
tin-base	50
zinc-base	50
Total	1,159,907

The following accounting of the forms of secondary copper recovery for 1967 shows that the amount of copper recovered in brass and bronze materials is more than 98 percent of the total (1). This situation suggests that optimum segregation of scrap items is imperative for maximum processing efficiency.

Form of Recovery	Short Tons
as unalloyed copper	
primary plants	343,277
other plants	79,777
brass and bronze	700,636
alloy iron and steel	2,805
aluminum alloys	28,148
other alloys	299
chemicals	4,965
Total	1,159,907

The equipment and procedures in the industries range from simple crucible furnaces for melting well-segregated scrap in brass foundries to large blast furnace installations for processing a wide range of low-grade mixed scrap in a smelting complex. A typical secondary copper smelter operation is shown in figure 4. Problems are encountered in the production of secondary copper which are common throughout the secondary metals industry. They include identification and segregation of scrap, flexibility in the variety of products to be made, and the availability



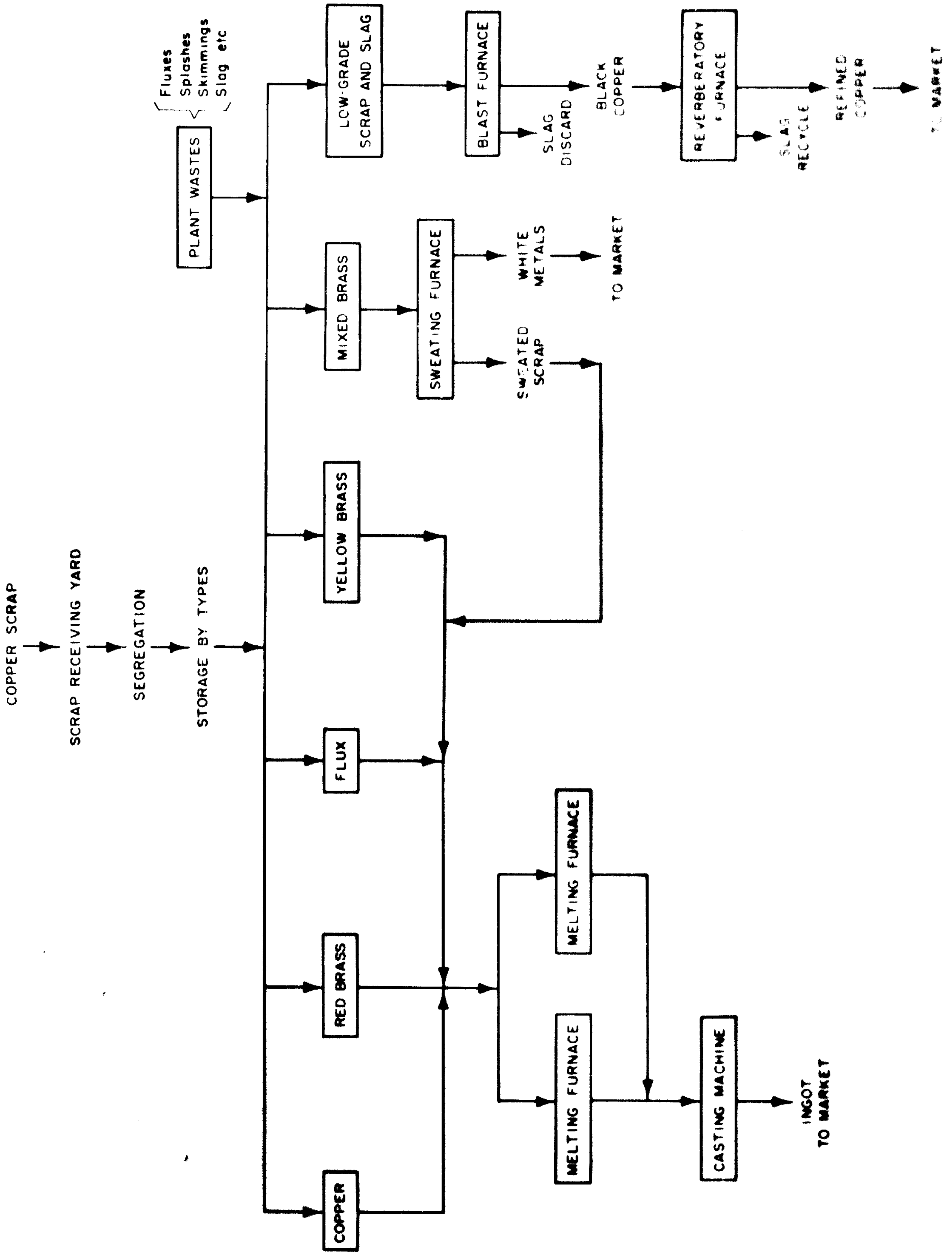


Figure 4 - Secondary Copper Processing

of raw materials in a highly competitive business. The processing problems include the complete extraction or utilization of values from plant wastes, such as fumes, dust, drosses, and slags, and removal of unwanted constituents from alloy melts to avoid costly dilution. Another common problem is that of receiving full payment for the valuable metals contained in semifinished products such as black copper and sweated white metals. Such products may contain significant amounts of silver, gold, tin, lead, zinc, aluminum, and other metals.

Secondary Lead

The total U. S. consumption of lead increased nearly 1.4 times from 1958 through 1967, while consumption of primary and secondary lead increased about 1.5 and 1.2 times, respectively. The materials listed in the standard classification(2) include only 11 types of scrap. The 1967 recovery of lead from scrap processed in the United States amounts to more than one-half million tons(1) as follows:

New Scrap	Short Tons
Lead base	71,829
Copper base	4,500
Tin base	578
Old Scrap	
Battery-lead plates	303,258
All other lead-base	155,892
Copper-base	17,711
Tin-base	4
Total	553,772

The form of recovered materials is below:

Form of recovery	Short tons
As soft lead	
Primary plants	2,538
Other plants	147,806
Other	
Antimonial lead	288,719
Copper-base alloys	17,795
Tin-base alloys	30
Other lead alloys	96,884
Total	553,772

The foregoing indicates that antimonial lead (battery plates) is the leading source of lead scrap materials. The relation of this industry to the automobile battery is evident in the fact that more than 50 percent of the total lead recovered is in antimonial lead. Other important types of scrap include electric cable sheath, machinery bearings, pipe, sheet and sweated solder.

Except for the lead blast furnace, secondary lead processes are largely kettle operations. Simple melting blending, and flux refining operations are carried out in a wide variety of kettles of numerous sizes. Most scrap battery plates are processed in the blast furnace to recover lead containing about 5 percent antimony. Some operators report heavy lead losses in fume, slag, and matte. A hearth furnace may be used to produce a relatively soft lead and a high antimony slag.

Both slag and fume losses are high. Soft lead can also be produced in kettle operations in which selective oxidation occurs at the surface and oxides of the impurities are removed mechanically. A typical plant layout is illustrated in figure 5.

Secondary Zinc

The annual United States consumption of zinc was only 1.4 times greater in 1967 than in 1958 and the corresponding consumption of secondary zinc was only 1.3 times the 1958 level. Zinc-base and copper-base alloys comprise the bulk of all zinc recovered in both new and old scrap as shown below for 1967.(1)

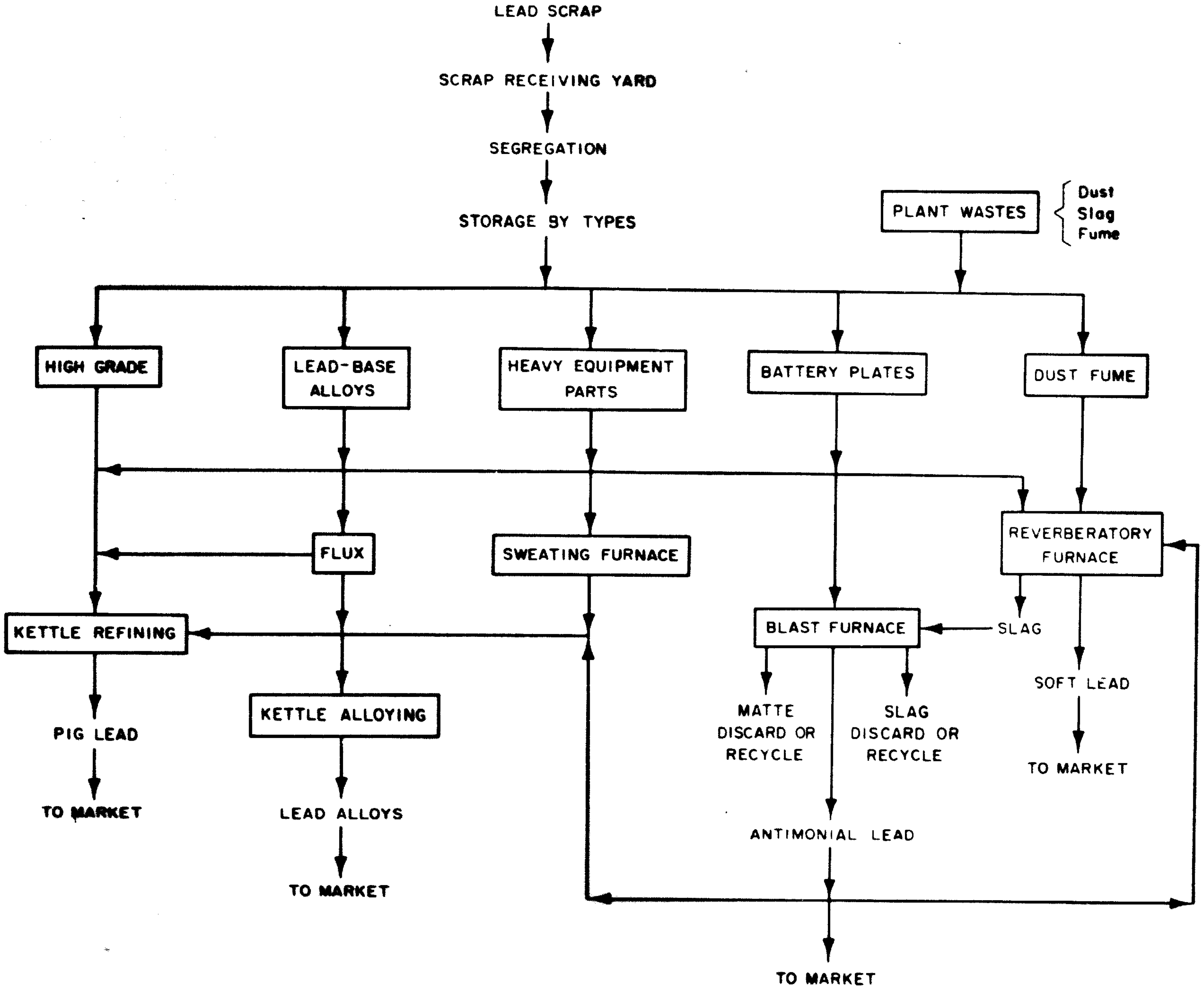
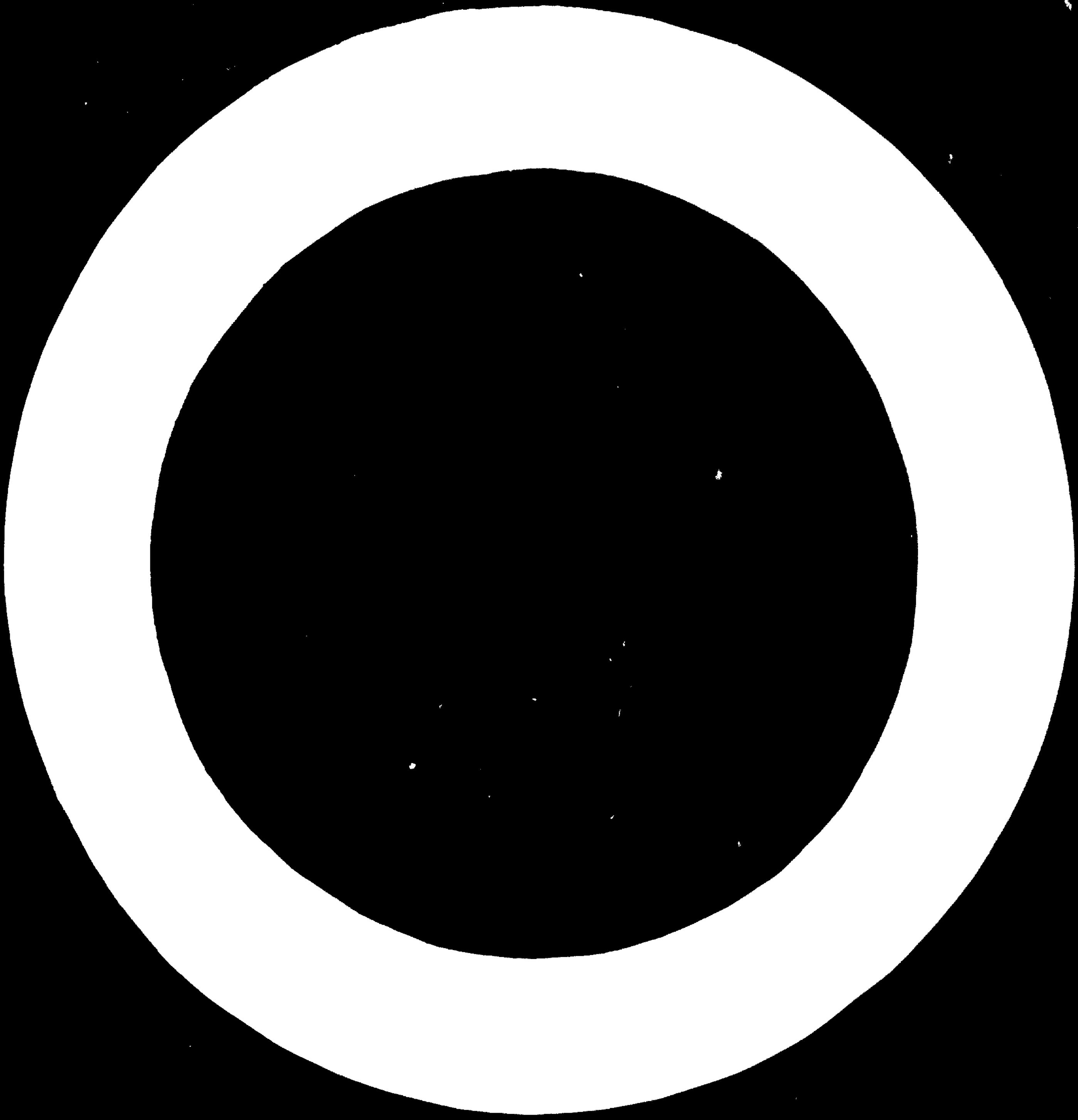
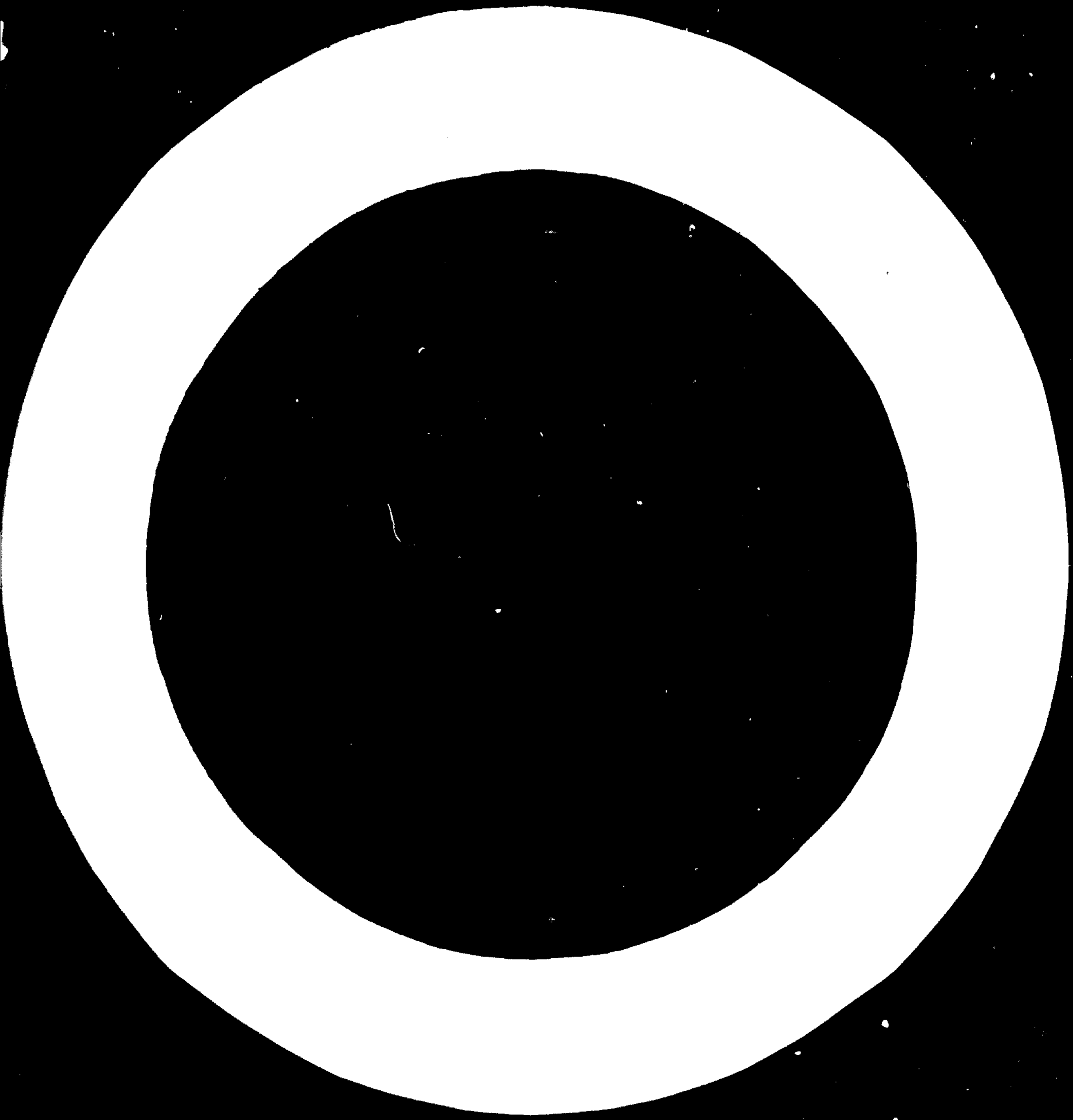


Figure 5 - Secondary Lead Processing





Kind of Scrap	Short Tons
New Scrap	
Zinc-base	129,774
Copper-base	106,637
Aluminum-base	2,895
Magnesium-base	234
Old Scrap	
Zinc-base	40,862
Copper-base	36,142
Aluminum-base	3,165
Magnesium-base	140
Total	319,849

The amount recovered in various forms of recovery is fairly well distributed except for the brass and bronze category which is several times greater than most other groups as follows:(1)

Form of Recovery as Metal	Short Tons
By distillation (slab zinc)	72,595
zinc dust	32,309
By remelting	6,366
In zinc base alloys	17,273
In brass and bronze	146,441
Aluminum-base alloys	6,145
Magnesium-base alloys	431
In chemical products (zinc oxide, lead free)	17,255
Zinc sulfate	9,536
Zinc chloride	11,236
Miscellaneous	262
Total	319,849

The standard classification(2) lists only 9 items of scrap, but it is obvious that most of the secondary zinc recovered is in the form of brass and bronze, which is not included in zinc scrap classifications. The most prominent types include 5 different die cast materials, old scrap zinc, new clippings, die cast dross, and galvanizers' dross.

Most of the die cast scrap alloys are usually refined or blended to suitable composition for new alloys. Galvanizers dross and occasionally die cast materials are distilled to produce zinc metal or zinc dust. Galvanizers dross and other high-zinc materials are also distilled and the vapor oxidized to produce zinc oxide products. Flux materials from galvanizers vats and processing pots are used primarily to produce zinc chemicals. Zinc-base dusts from filters, precipitators, scrubbers, and cyclones may be used to produce zinc sulfate or they may be smelted to produce zinc metal. Unalloyed zinc metal is used primarily in the production of small castings and for galvanizing.

Since relatively few types of scrap materials are processed by the secondary zinc producers, the problem of identification and segregation are not as critically important as they are for the other secondary metals. The major problems involve purchasing and storing; the processing technology has been well developed. However, the cost of equipment, such as distillation retorts and fume and dust collecting equipment, is high as in all metallurgical processes. The common problem of waste disposal is growing in this industry as environmental issues become more critical.

Figure 6 is a diagrammatical representation of a typical secondary zinc operation.

Identifying Opportunities

It can be assumed that no opportunities can exist in the business world unless some minimum profit is possible. Obviously, the potential profit to be expected from a plan or hypothetical operation would be

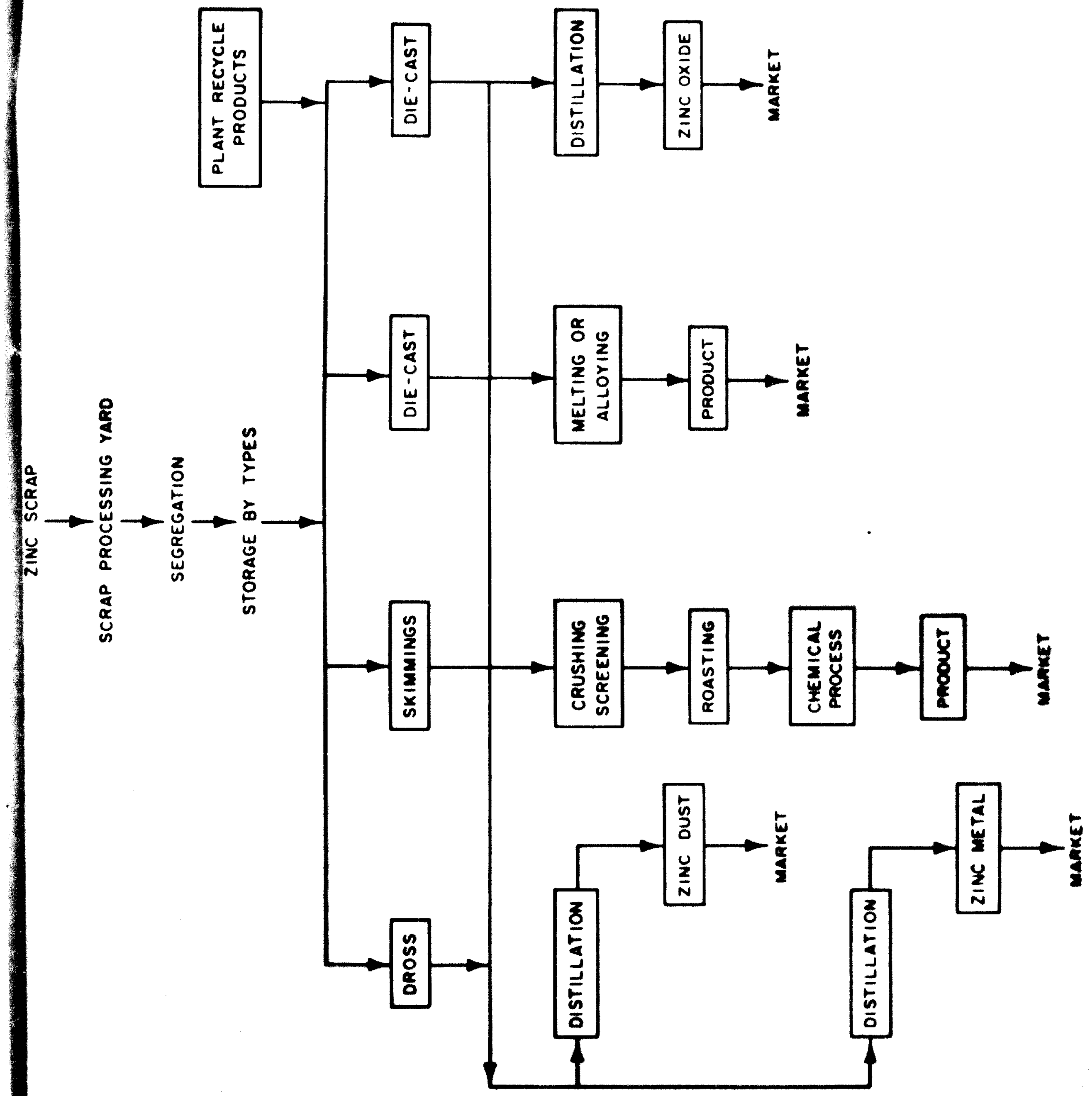
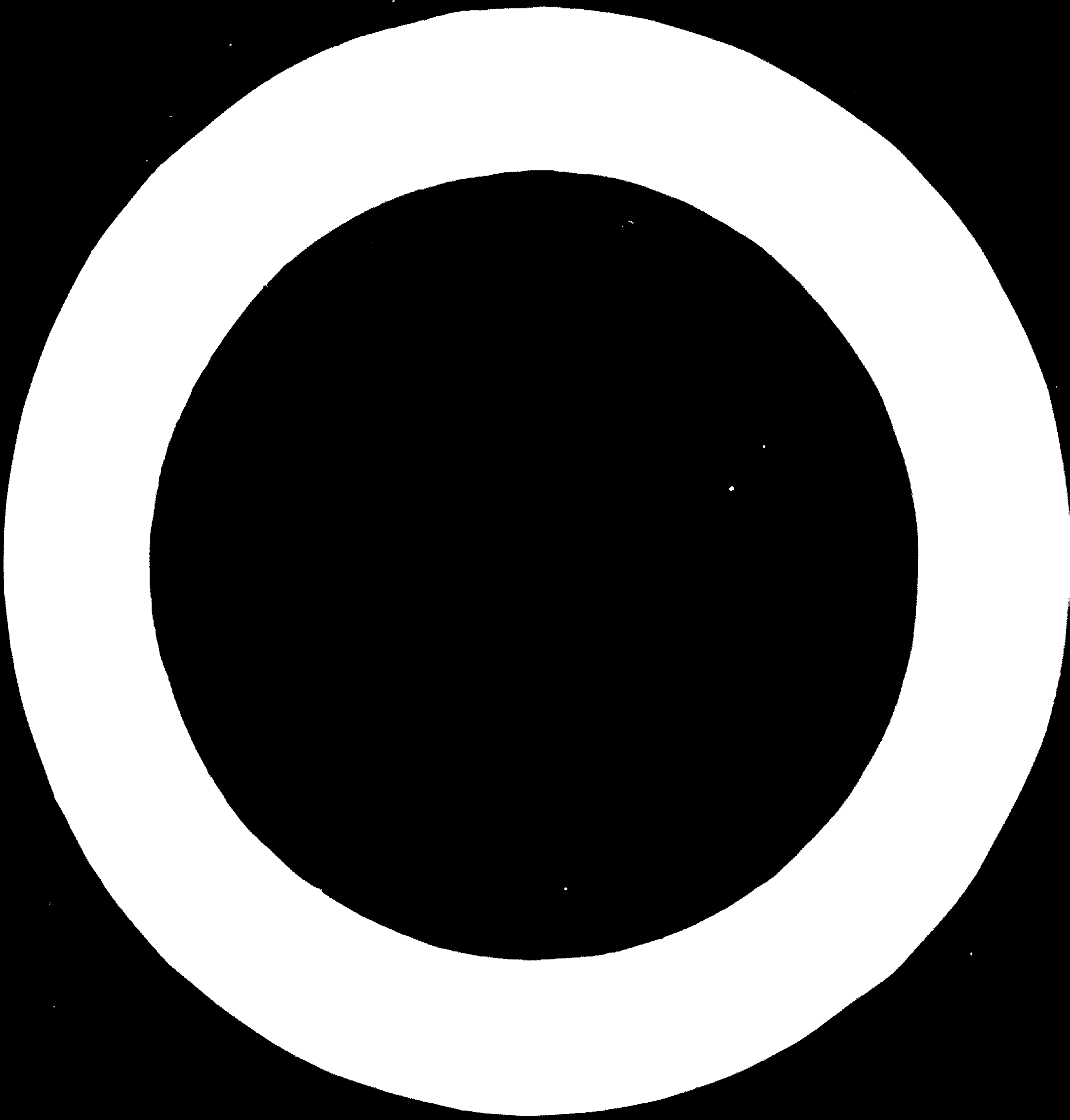


Figure 6 - Secondary Zinc Processing



roughly proportional to the anticipated volume of business. This might be expressed as the difference in the cost of raw materials plus operating costs, and the market value of plant products. If these considerations appear favorable, and if the long term supply of raw materials can be assured at a reasonable price, it should be possible to produce marketable secondary metal products profitably in most any country simply by employing current technology. If the potential supplies of scrap and other metal-bearing wastes are comparable to those of the United States, for example, the quantities of materials to be handled and the volume of production should also be comparable. It is reasonable to assume that the price of raw materials and the volume of products will rise and fall with corresponding fluctuation in the demand. Ordinarily, the volume of scrap metals increases with increased short supply so that the ability to anticipate such changes well in advance of the event is an obvious advantage in the competitive secondary metals industry.

Available methods and equipment are quite adequate for the scrap materials on the current market or those that can be anticipated in the near future. There is, however, a decided advantage for the newcomer to design a new plant to employ only the most efficient processes and the best types of equipment to process the most profitable types of raw materials. It follows that considerable flexibility to handle any one or a variety of scraps at full plant capacity is essential for optimum return on the investment. It is equally important to provide for the maximum recovery of values from in-house materials such as flue dust, drosses, skimmings, and other materials. Since the quantities of these materials are markedly less than those normally flowing through processing channels, it is necessary to either collect and sell them, or store and process them intermittently. Most processors prefer to sell them if possible because intermittent processing is not normally economical. Except for possible new and revolutionary discoveries or developments, the only other opportunities would be realized by obtaining an appropriate relaxing of product specifications, particularly in the foundries and die casting plants. There are many tons of rather high-quality alloys used in the production of consumer goods that do not require the strength, dimension stability, or other specific physical properties of the alloys being used. Many items are strictly decorative; othem, such as toys are simply shapes, and the exact physical properties of the materials used to produce them are of little importance. Perhaps a better specification would require only that they be solid at ordinary temperatures and stronger than wood or plastic. Other more rigid specifications tend to invite the introduction of the plastics and other substitutes.

Another alloy specification advantage may be realized simply by reducing the number of standard alloys offered by the industry. It appe totally unreasonable to suggest that all of the many different alloys now being marketed are rigidly essential in view of the fact that the differences among so many of them are quite trivial. Accordingly, it might be practical to formally reduce the number of standard copper-base alloys, for example, perhaps to one half the number now produced without significantly changing the availability of essential alloy physical properties of strength, weight, luster, and others. The result would marked reduce the high cost of close alloy composition control and the expensive practice of diluting impurities with refined metals or high-grade scrap.

One other management-type of opportunity might well be considered by the developing countries. It is possible that two or more countries may find mutual benefits in negotiating bartering, or purchasing agreements by which metal scrap or other materials could be exchanged. For example, it appears to be impractical to process high-temperature alloy scrap such as jet engine turbine blades in the United States but it is profitable to ship this material to European processors. If some of the developing countries have a demand for significant amounts of metals which cannot be supplied from domestic resources, it may be highly practical for such countries to import scrap and process it for domestic consumption. Obviously such opportunities may be difficult to pursue to a satisfactory conclusion.

Innovative Processing

Aside from the normal return derived from suitable investments in conventional processes, and benefits of clever management, opportunities must be made to happen since they seldom occur except by design. According to this point of view, the plant operator must look to potentially better equipment, improved processes, or new sources of preferred raw materials for new opportunities.

The metallurgy research organization of the U. S. Bureau of Mines has investigated such possibilities in secondary metals processes over the past several decades. Numerous publications have been released and many interesting processing possibilities have evolved. Concluding discussions are directed to several such investigations which disclose potential opportunities for developing countries. They include vacuum distillation as a possible substitute for conventional distillation of zinc or other of the more volatile metals; a new type of vacuum retort which permits gas heating instead of electrical induction heating, and a possible long-life substitute for the less durable conventional zinc distillation retorts. Other investigations are described in which two different types of scrap are used as mutually effective refining agents. Finally, several new processes are described which appear to encourage more extensive use of hydrometallurgical processes in nonferrous secondary plants.

Vacuum Distillation

Distillation at reduced pressure offers several important advantages over conventional methods of refining volatile metals. They are so important in fact that low-pressure distillation has been the subject of many research studies (5), (6), (7) for many years. The most important advantages include high rates of evaporation at relatively low temperatures, increased selectivity in the separation of charge constituents, and protection of the distilled product metal against oxidation or other contamination. The disadvantages of such a system formerly included the extra cost of the vacuum system and the dependence upon electrical heating for such systems. An investigation (8) by the Bureau of Mines was planned to achieve several objectives as follows:

1. Increase the rate of evaporation above the rates in conventional operations.

2. Produce an improved retort to provide extra long life at minimum cost.
3. Provide a system to save fuels by permitting low operating temperatures.
4. Design the system for gas heating.

The design and ultimate distillation unit are shown in figures 7 and 8 respectively. The stainless steel shell protects the carbon retort from corrosion on the flame side and the carbon retort liner protects the stainless steel shell from attack by the retort charge. The water-cooled condensing system shown was designed to condense zinc to the solid state. A different air-cooled condenser (not shown) was employed to condense zinc to the liquid state with arrangements to permit the removal of liquid zinc without disturbing the vacuum within the retort.

Zinc was distilled from dross and die cast scrap with the following results: More than 99 percent of the zinc was recovered as a condensate containing 99.8 to 99.9 percent zinc. Atmospheric pressure distillation recovers 95 to 98 percent of the zinc at a purity of 99.5 percent. However, the distillation rate was about 50 pounds of zinc per hour at a retort temperature of only 650°C and the pressure ranging between 50 and 100 microns. In conventional equipment the rate of evaporation at this low temperature would be insignificant at atmospheric pressure.

The service life of the retort appeared to be completely satisfactory. It was operated for 1,180 hours at 665°C to 875°C on the fire side to produce distillation of metal at 650°C. Cyclic thermal stresses caused a hairline crack which was readily patched, and the retort operated for an additional 470 hours at which time the experiments were terminated. Except for minor repairs the observed performance of the retort and the

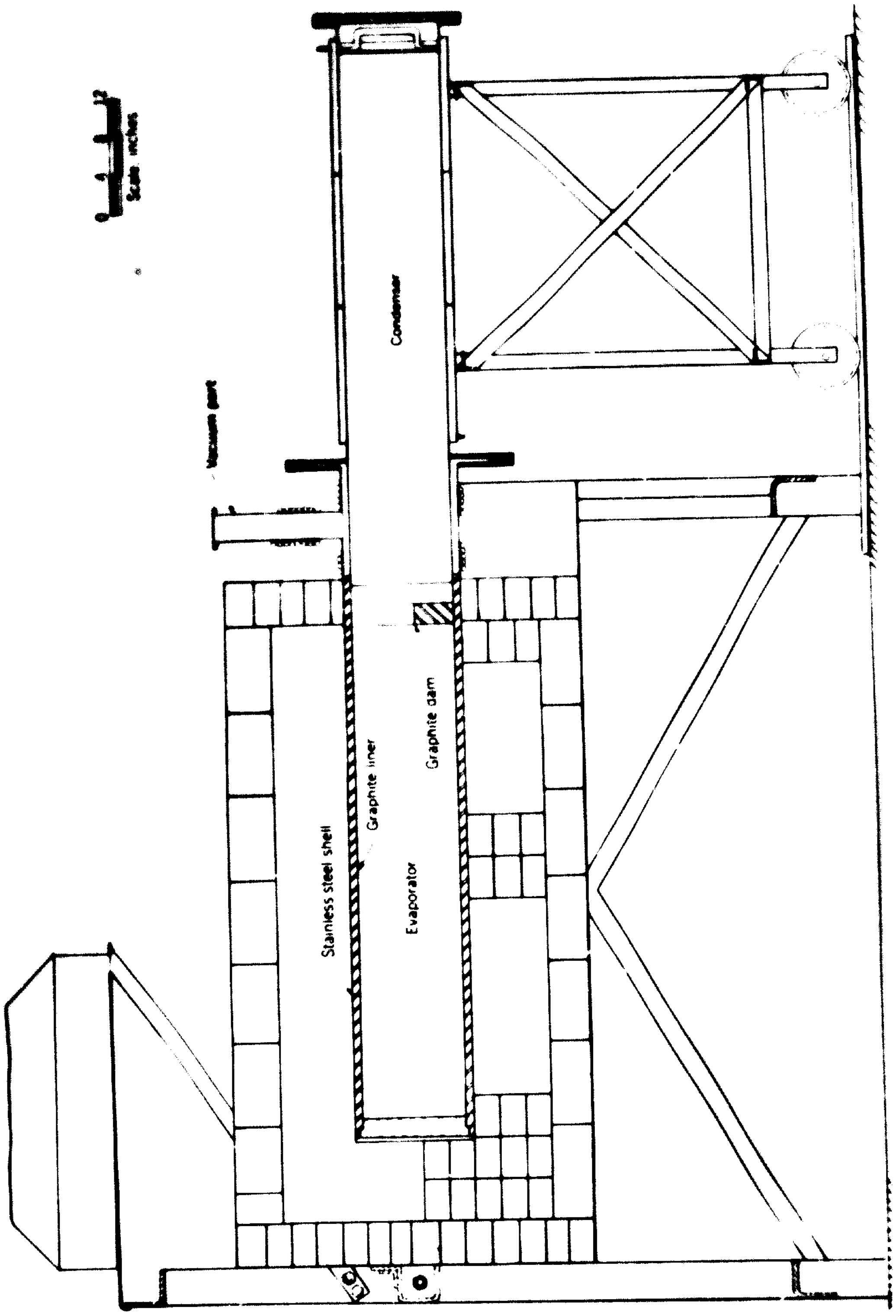


Figure 7 - Gas-Fired Vacuum Distillation Retort Design

Policies, Incentives, and Programs

Recommendations concerning the introduction of a new or expanded secondary metals industry in developing countries are basically the same whether addressed to the individual countries or to their citizens or corporate groups. However, it is not likely that an individual or a small group would be able to initiate and maintain a significant secondary metals industry within a reasonable time without the endorsement and support of the Government. Limited individual or small-group efforts would probably preclude a result of significant national importance.

This immediately suggests that several important official actions should be taken by a country considering support of a new or expanded industry. One common procedure is to establish an official commission or committee to develop sound initial plans and procedures for implementing them. The commission type of organization is usually more effective as a relatively small body of carefully selected members appointed on a long-term basis as consultants, advisors, and managers. Some commission members could be contributed by helpful organizations such as UNIDO or perhaps a neighboring country. Other members could be selected from professional citizen groups, and some could be hired from other countries. The major duties would include the following:

1. Recommend governmental policies needed to promote and foster a prosperous industry. Policies involving a government-supported or government-operated secondary metals industry should involve an official

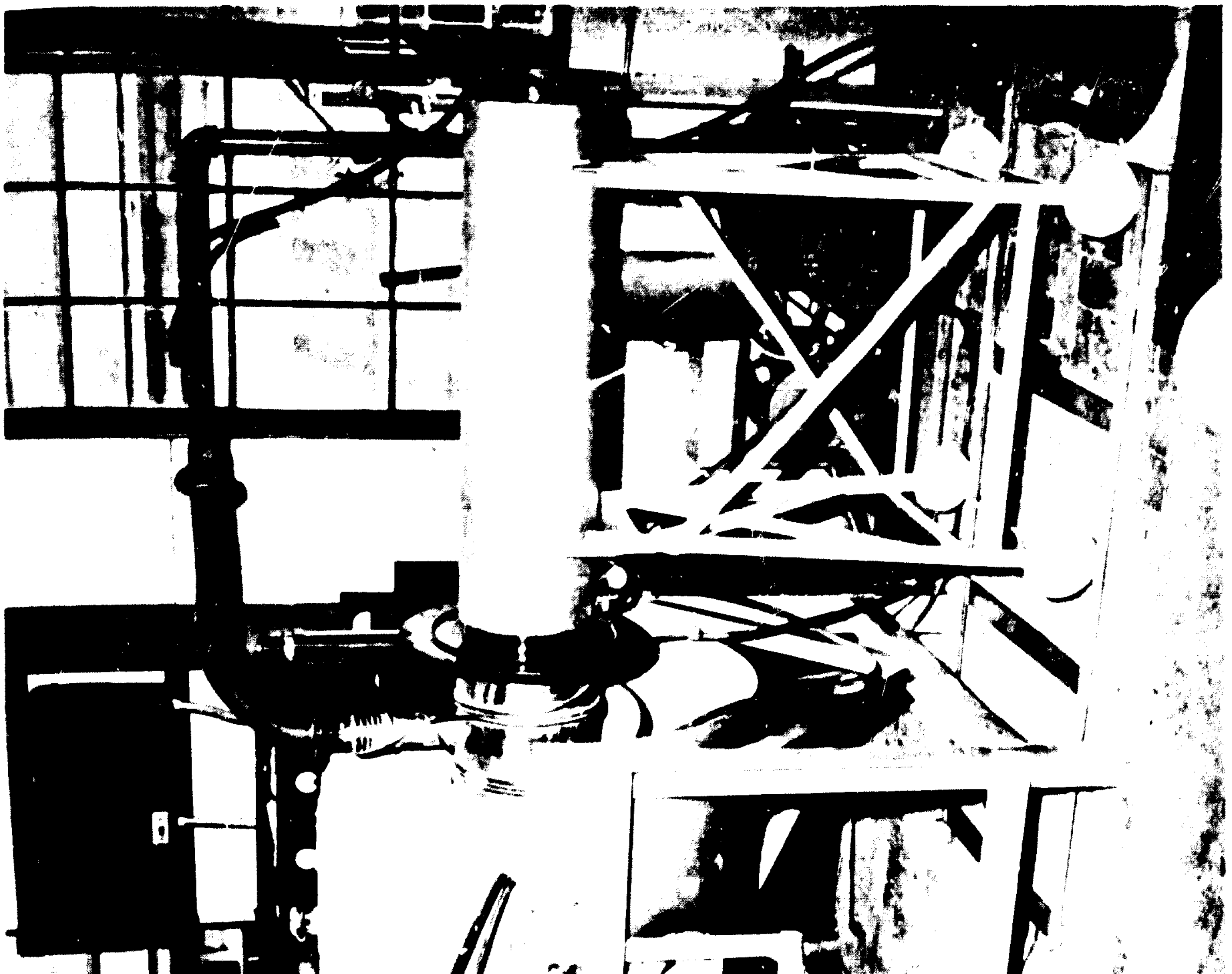


Figure 8 - Gas-Fired Vacuum Distillation Retort in Operation

shell suggests a full useful life of several thousands of hours. Conventional zinc distillation retorts normally are completely spent in less than 1,000 hours. This type of distillation system would be applicable to other metals such as cadmium, magnesium, zinc, and volatile intermetallic compounds.

Processing Zinc-Base Scrap

Sal skimming addition

The use of one processing waste material as an agent to refine another offers several interesting possibilities. In one investigation (9) it was found that sal skimmings could be used very effectively to remove unwanted aluminum from molten die-cast scrap containing 3 to 4 percent aluminum. If a supply of die-cast scrap is not uniform in composition it is normally mixed with materials of slightly higher purity to form new die-cast alloy. If not, it is distilled in conventional retorts charged with a mixture of zinc-base die-cast scrap and galvanizers dross. During the above investigation it was found that the zinc chloride in sal skimmings ($ZnCl_2 \cdot NH_4Cl$ and ZnO) will react with excess aluminum in a subgrade melt of die-cast scrap according to the following reaction.

$$2Al + 3ZnCl_2 \rightarrow 3Zn + 2AlCl_3$$

The aluminum content of the resulting alloy can be reduced to 0.01 percent. The zinc metal generated during the reaction collects with the melt and the aluminum chloride evaporates away from the melt.

Removing solid phase impurities

The separation of solid and liquid phases in molten metal systems is not new to metallurgy but it might well be applied more extensively than it is today in the secondary metals industry. The well-known technique of collecting gold in molten mercury and then filtering out the solid gold amalgam by passing the mercury through a chamois skin was perhaps among the first metallurgical processes ever devised. Several years ago the Bureau of Mines investigated the use of centrifugation as a means for separating liquid and solid phases that may be present in molten scrap metal (10). In later experiments it was found that iron chloride could be used to remove aluminum from zinc-base die-cast as a solid phase (11, 12), according to the following reactions:

$$2FeCl_3 + 2Al \rightarrow 2Fe + 2AlCl_3$$

$$2Fe + 5Al \rightarrow Fe_2Al_5$$

The equivalent reaction is:

$$2FeCl_3 + 7Al \rightarrow Fe_2Al_5 + 2AlCl_3$$

The aluminum chloride volatilizes, and the solid intermetallic iron-aluminum compound is filtered out of the molten alloy. The Bureau of Mines patent (13) claims a need for only 0.286 mol. of $FeCl_3$ to remove one mol. of aluminum.

In a similar process, two metallic scrap materials can be processed together as mutual refining agents to accomplish the removal of aluminum and iron from zinc-base melts. Since die-cast scrap may contain unwanted aluminum and galvanizer dross contains unwanted iron, it may be profitable to process them together to form the aluminum-iron intermetallic compound and remove it from the melt as a solid phase. Bureau of Mines investigators found that melting the two types of scrap together in suitable proportions would form solid intermetallic Fe_2Al_5 which could be separated from the liquid metal by simple filtration or centrifugation techniques. From 87 to 92 percent of the contained zinc is recovered in a product containing about 0.02 percent iron and 0.20 percent aluminum. The aluminum can be removed to less than 0.01 percent by adding zinc chloride.

Mechanical processing

Many problems are encountered in the preparation of scrap materials before processing. One typical example is the removal of insulating materials from aluminum or copper electrical conductors. For many years the secondary plants have either burned the insulation off prior to melting or in some cases it is burned off during the process, such as in the copper-scrap blast furnace. Several years ago, the Bureau of Mines developed a rather simple and effective spiral separator (14) which, in effect, separates the metallic and non-metallic constituents from scrap such as cable that has been chopped into short sections and hammered to break away the insulation. A tilted rotating device shown in figure 9 will, because of the differences in sliding friction, cause the short metallic sections to move in one direction parallel to the maj axis of the device while the insulation moves in the opposite direction. Typical results are illustrated in figure 10.

Electrolytic processing

The use of electrolytic methods for extracting and refining scrap metals has not received extensive consideration for several reasons. Perhaps the greatest problem is the wide variety of metal constituents that must be accommodated by wet chemical methods to produce satisfacto electrolytes and electrodeposited metal. The possible use of mercury a

Figure 9 - Spiral Separator

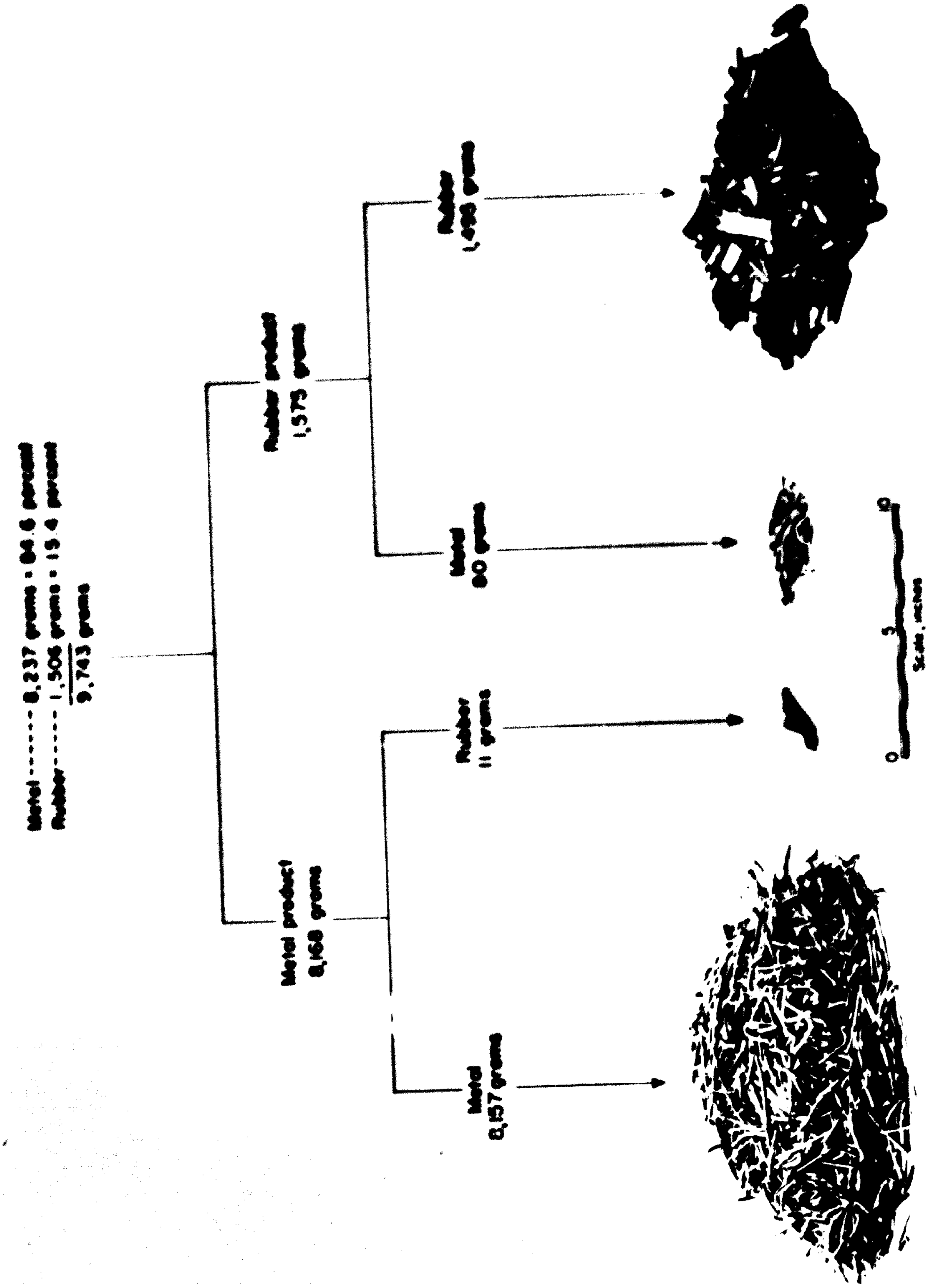


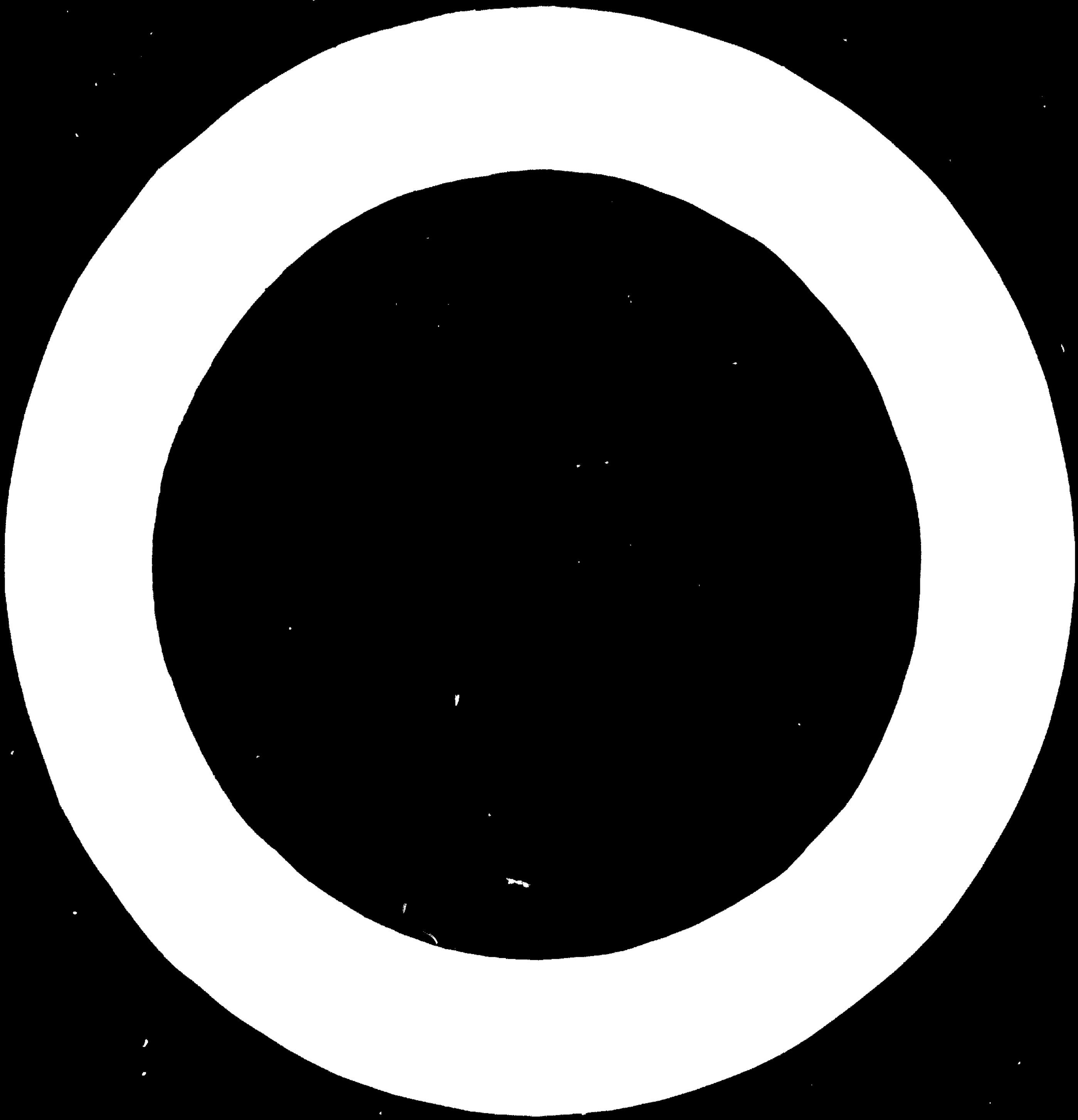
Figure 10 - Spiral Separator Performance

an amalgam electrode and as a vehicle to extract and transport metals rather selectively was investigated several years ago (15, 16) in one phase of an effort to develop more efficient methods for processing iron-bearing zinc and tin alloys. Mercury was used to leach tin from hardhead and zinc from galvanizers dross, and these were subsequently electrodeposited as high-purity metals. The zinc recovered from galvanizers dross was 99.99 percent pure at an extraction efficiency of 98 percent. The tin recovered from hardhead was 99.99 percent pure at a recovery efficiency of 81 percent. The high-purity metals were produced by the same methods, but in separate systems. A simple vertical amalgam electrode was developed (17) to simplify the design and minimize the required mercury inventory. The experimental cell is shown in figure 11. It would appear that other applications of this technique would be equally successful.

Wet chemical processing

The normal problems encountered in the wet chemical processing of scrap metals have been mentioned above. Although the use of processes such as the ammonia-carbon dioxide leaching of copper scrap (18) have not been employed extensively in the United States, some are technically sound and would probably be economic under slightly more favorable conditions. The ammonia process would probably be more successful if slight improvements could be found in the purification of pregnant solutions and the hydrogen autoclave reduction operations.

The Bureau of Mines had some success in the recovery of lead and copper from lead blast-furnace matte (19) using brine and water leaches. A laboratory-scale process was developed in which three valuable



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attitude and objective aligned to the prudent salvaging, processing, and reuse of industrial and municipal reject materials, either domestic, foreign, or both. However, it is not likely that the best policies could be developed without benefit of an intensive study of the resources, capabilities, and economic climate within the country in question.

2. Suggest new laws and regulations needed for the implementation of new programs. It has been shown on several occasions that legislative steps can be taken by countries and municipalities to encourage the ultimate collection and utilization of scrap. For example, old autos are much easier to salvage in American communities where it is illegal to abandon them on the streets or vacant lots.

3. Determine the most satisfactory division of financial burdens among the private, governmental, and business sectors of the country.

It is rather obvious that none of the above can be completed without extensive study and evaluation of alternatives. For this reason it is important to activate special study groups at the earliest possible date. If, in the initial considerations, there appears to be a reasonable justification for serious planning, the commission or study teams hired by the commission should completely analyze the situation in terms of raw materials resource, processing capability, and the size of the market for potential products. If the results of such studies appear promising, additional studies should be made to determine costs of production, probable selling price, and intangible benefits such as waste disposal and pollution control. There are innumerable unique situations in any country which could have a direct impact upon the net result. Obviously, the extent of any venture leading to the establishment of a new or greatly expanded industry should be based upon predictable potentials rather than unproven assumptions. Particular caution should be exercised if, for example, the amount of available scrap is found to be high initially but likely to diminish rapidly when a processing plant begins to operate.

The planning and programming phases of the commission should be pursued systematically, beginning with a complete listing of objectives. These would probably include the following procedural phases:

1. Assistance

Since UNIDO is interested in the possible development of secondary nonferrous metals industries in the developing countries, the most important assistance to those countries is sound expert advice and guidance, preferably by a team of professionals appointed specifically to the task of obtaining and evaluating all pertinent facts. Such a team should assume the responsibility of making initial investigations and recommendations for subsequent actions. If the country in question has this capability and prefers to take the responsibility, then the UNIDO teams or other advisors should stand ready to give additional assistance. All of the following phases of industrial development will require the services of experienced professionals.

2. Characterize the Scrap Resource

a. Determine, as accurately as possible, the exact availability and cost of each type of scrap originating in the heavily populated areas and estimate the rate of growth or decline in the total amount of these materials if a substantial amount is collected and processed by a new plant of specified capacity.

b. Identify the problems likely to be encountered in the movement of scrap from its origin to the processing plant.

c. Determine the relative economy of one central processing plant to receive and process all types of scrap versus several dispersed smaller plants designed to process aluminum, copper, lead, or tin scrap only.

d. Locate dependable foreign sources of scrap if the domestic supply is not sufficient to supply a plant of a desired capacity.

e. Estimate amounts and types of new scrap items likely to become available some time in the future and how soon currently-available types may no longer be available.

3. Creating Incentives for Developing a Scrap Resource

a. Evaluate various types of actions including laws and regulations to stimulate the collection and delivery of scrap to central receiving stations or preparation yards.

b. Establish convenient purchasing centers to receive scrap delivered by citizens. Provide bonus payments for large deliveries.

c. Provide tax refunds or allowances for delivery of specified amounts of scrap.

d. Provide regulations to prohibit disposal of metallic goods or scrap except at specified collection centers.

e. Obtain technical assistance in the development of a complete collection and preparation system.

f. Establish a metal collection agency to manage and control scrap collection and delivery to the processing plants.

4. Evaluate Potential Processes

a. Obtain assistance and guidance from experienced technologists and economists in the analysis and evaluation of processes most suitable for the types of scrap available.

b. On the basis of cost of production versus product value, select those processes offering the greatest advantages and highest probability of success.

c. Work up preliminary tentative plant designs incorporating the best opportunities offered by modern technology.

d. Complete the design of a demonstration plant which can, if successful, be expanded into full-scale industrial production.

e. Determine, as accurately as possible, the total cost of the facility by the techniques of process cost and evaluation.

5. Construction and Operation

a. Obtain finances for the construction and operation of the most promising process as determined through process evaluation and analysis.

b. Construct demonstration plant and operate through a preliminary period needed to optimize all control parameters.

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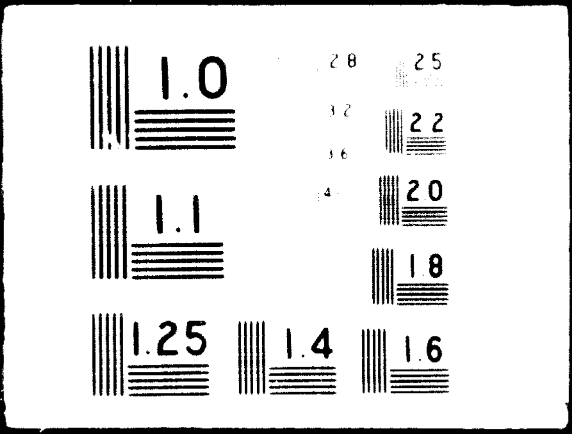

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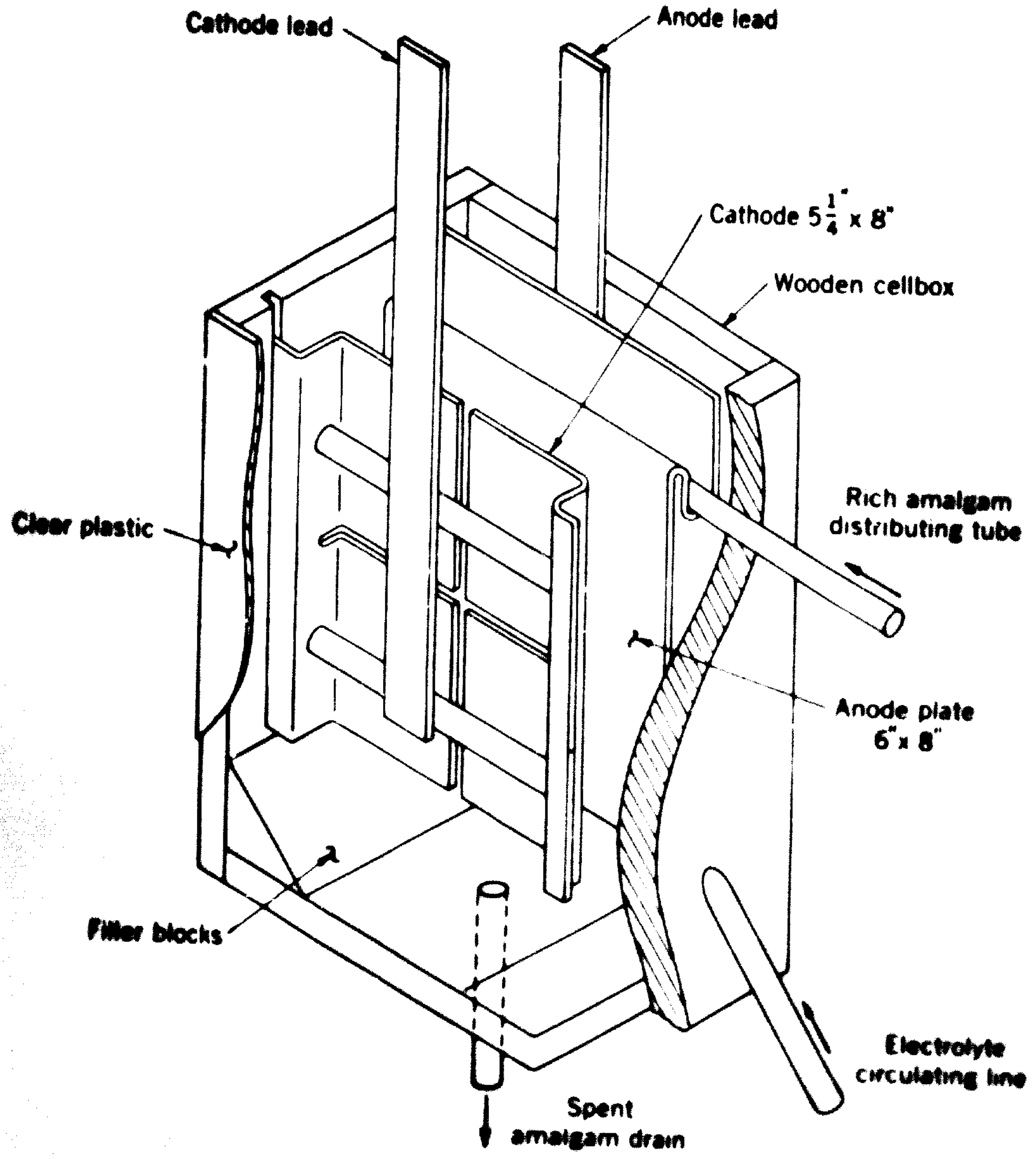

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Figure 11 - Experimental Amalgam Electrolytic Cell

constituents in the matte (copper, lead, and iron) were recovered. The roasted matte was leached with water to recover copper. A subsequent brine leach extracted the lead and the iron oxide residues were reduced to produce pig iron. Metallic copper was cemented from solution, and lead was recovered as a mixture of $3PbO \cdot PbCl_2$ and $Pb(OH)Cl$. Copper and lead recoveries were 89 and 96 percent respectively.

Literature

In closing these discussions, it is appropriate to cite pertinent literature that may suggest other opportunities. Although the subject of nonferrous secondary metals has not received the extensive technical press coverage that it warrants, publications have appeared more frequently in recent years, and the subject is now receiving more of the scientific and technologic consideration it deserves. In order to exploit such information to the fullest extent, a bibliography has been added to direct the reader to other pertinent data.

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