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Evaluation, Extraction, and Recycling of Certain Solid Waste Components

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EVALUATION, EXTRACTION, AND RECYCLING OF CERTAIN SOLID WASTE COMPONENTS

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16. Abstracts

The constituents of municipal solid waste are identified along with relative weight percentages typically found. Recycling priorities are established with respect to realistic criteria. Though the study was performed for Erie, Pa., concepts may be applied elsewhere. Paper, ferrous metals, aluminum, and rubber tires are listed, in that order, with respect to desirability of extraction. Tin cans, glass, and plastics are listed next under additional criteria. A survey of current technology is presented that briefly discusses unit processes as well as complete systems under development. Many unit processes are found to be an outgrowth from mining practices. A device called the "Bowerman Classifier" is presented and incorporated into a system with potential to separate preprocessed municipal waste. The device operates on the principle of Stoke's Law applied to a moving fluid. All else being held equal, settling velocity will be proportional to density and thus a separation may be effected.

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17c. COSATI Field/Group

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PREFACE

This report is the product of the work performed under Grant No. 1-G06-EC-00292-01 from the Bureau of Solid Waste Management to the Health Department of the County of Erie, State of Pennsylvania. A team of experts, which provided competence in the fields of Solid Waste Management, Civil Engineering, and Mechanical Engineering, was assembled for the study by the Great Lakes Research Institute (GLRI), under contract to the Health Department. This team included the following individuals:

Prof. Frank R. Bowerman, School of Engr., Univ. of Southern Calif.

Dr. Ward W. Knockemus, Asst. Prof. of Chemistry, Pennsylvania State University, Behrend Campus

Dr. Halit M. Kosar, Prof. of Engineering, Gannon College

Dr. David P. Spalding, Senior Research Assoc. in Chemistry, Pennsylvania State University

This research group pursued three major objectives, as funded by the research grant:

1) Determination and ranking of constituents contained in municipal solid wastes in the order of beneficial results from their extraction, from the standpoint of major present and projected disposal methods.

2) Survey of current proven methods of extracting constituents from solid waste.

3) Draft of Specification for devices and subsystem for extraction of constituents from solid wastes; development

of a proposal for the design of an integrated pilot extraction system.

The work reported here accomplished these objectives and has produced the design of a prototype installation for the development of processes for the efficient recovery of useful components from municipal solid wastes.

SECTION I: INTRODUCTION

This report is the result of a collaboration among the Erie County Health Department, the Office of Solid Waste Management Programs, and technical expertise assembled by the Great Lakes Research Institute.

As the responsible agency for health maintenance in Erie County, the Health Department has long recognized the importance of the environment as a major determining factor in the quality of community health. Although cleaning up the environment is a costly and long-range goal for a health department to pursue, Erie County felt it could not afford to deal only with today's health problems without planning for a better tomorrow.

This general consideration for the effects of the environment on community health led to a more specific interest in the problem of solid waste management. The Health Department felt that Erie County would benefit greatly from a compiled summary of the state of the art of waste treatment technology as it applied to variously constituted aggregates of solid waste, particularly since this up-to-date overview might lead to new insights in the treatment and/or recycling of the solid wastes. In conjunction with this initiative taken by the Health Department, the Office of solid Waste Management Programs agreed to fund an investigation under these general guidelines. The Health Department contracted this investigation to a specialist research and consulting firm in Erie, Pennsylvania, the Great Lakes Research Institute (GLRI).

The project research team assembled by the GLRI first met on August 5, 1970, under the chairmanship of the project manager, Dr. Spalding, to share their knowledge on solid waste management technology, and to develop a working plan with which to fulfill the funded objectives. While it was agreed that all members would contribute to the total effort, the prime responsibility for determination and ranking of constituents (Objective 1) was assigned to Dr. Knockemus (see Section II), and the prime responsibility for the technological review (Objective 2) was assigned to Dr. Kosar (see Sections III and IV). Prof. Bowerman assumed the prime responsibility for reviewing and integrating these two efforts and for developing the proposal for the integrated extraction system (Objective 3; see Preface, above, and Sections V - VIII). The Plan adopted for accomplishment of these project objectives was to (a) visit the centers of relevant technology (b) study and selected references (c) prepare interim reports on objectives 1 and 2 and (d) hold a project review meeting to plan the accomplishment of objective 3.

As the review of relevant information proceeded, new insights and ideas did indeed develop. The major inventive contribution was made by Prof. Bowerman, who suggested a fluid settling tank classifier which would preform comprehensive fractionation of mixed solid wastes. Prof. Bowerman's idea has been incorporated into a suggestion that a pilot, or prototype, plant be built to study and demonstrate the feasibility of the new device. This suggestion is included in Sections V - VIII.

While much thought and preparation have been given to this suggestion, in order to make it as detailed and workable a plan as possible, this report has no pretensions of specifying every detail of the project as a completely optimized and unalterable decision. Where there are indicated quite specific building parameters (brand names of components, power potentials and the like), the reader should understand that these details are "for instances," parameters which are recognized as useful possibilities, but which await the on-going development of the project for a final decision on their implementation.

SECTION II: CONSTITUENTS OF SOLID WASTE

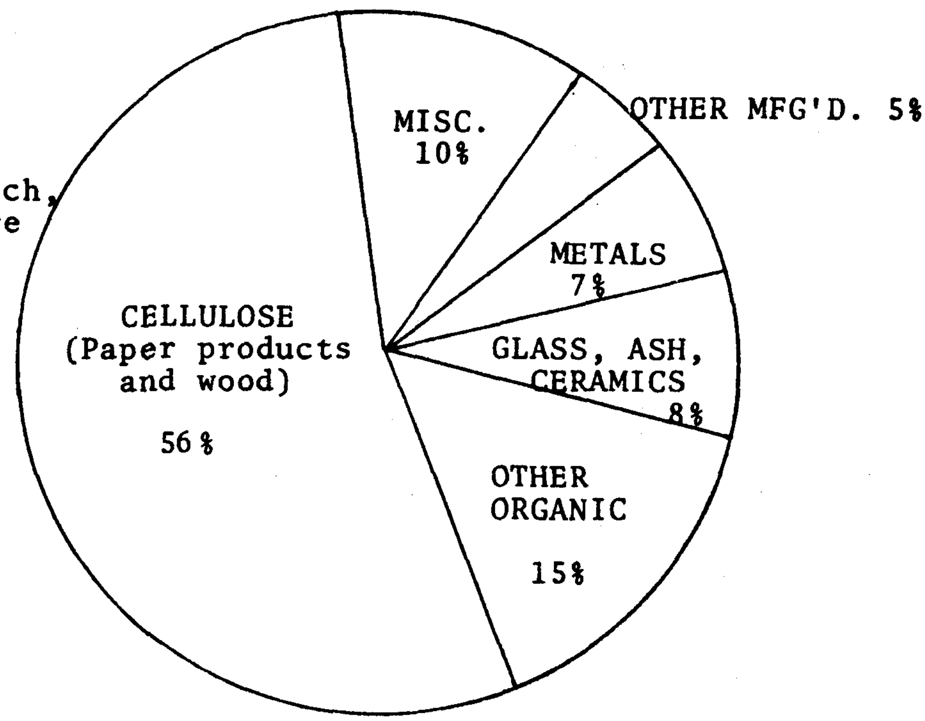
Solid waste consists of practically anything solid that is discarded, whether it comes from a home owner, hospital, restaurant or corporation. Its domain is as broad as the range of products man prepares from the raw materials provided by nature. Municipal solid waste is a subclass of this enormous collection. It is defined here to include garbage, rubbish, bulk wastes, and street refuse generated by people in their homes and commercial establishments, but it excludes that generated by industrial operations.

Many studies have been made in this field, and the variation in composition of such material in modern American cities is surprisingly small (see graph below) (18).

Miscellaneous:
dirt, vacuum catch, adjusted moisture

Other Organic:
rinds, meats, fats, leaves, grass, etc.

Other Manufactured:
plastics, rags, leather, rubber, paints, plastic-coated paper, wax cartons



This composition is further broken down in Appendix A; for present purposes, however, the figures on the graph may be taken as typical. Slight regional and seasonal variations from this composition would not affect the major design considerations for the pilot plant proposal (see Sections V, VI, and VII, below).

If the composition of these solid wastes is constant, notes Richard D. Vaughan, formerly Director of the Office of Solid Waste Management Programs, E.P.A., the quantities involved are certainly not. The 360 million tons of solid waste presently produced by Americans each year (of which 250 million tons comes from households alone) will double within the next 15 years. Behind this statistic, Vaughan points out, grows the urgency of two already serious national problems: what to do with all this garbage, and how to replenish the resources which are producing it.

Recycling - turning old wastes into new resources - presents a neat, virtually ideal solution to both these problems: conservation of resources is achieved, and a place is found for the inundating mountains of solid waste. Unfortunately, economic pragmatics, in light of current technological development, makes complete recycling unattainable at the present time. The establishment of recycling priorities for various components of solid waste must therefore continue to develop under the following criteria:

1) The component is immediately reusable without alterations or repair.

2) The component is made up of a material that originated from a natural resource in fixed, short, or dwindling supply.

3) A known technology can recover the original valuable material in the discarded item at a reasonable cost.

4) The solid waste component has a chemical composition that makes it potentially useful as a fertilizer, soil conditioner, or fuel.

5) Current research indicates that a technology will be available in the near future to transform the currently useless item into something of value.

Under the above criteria, current proven technologies and present markets establish the feasibility of salvaging the following components of solid waste in many regions of the country:

1) Clean, bundled newspapers free of magazines, photocopy papers, or other treated papers containing clays, resins, starches, hot-melt adhesives, or other objectionable additives. Though the market fluctuates, this clean waste paper used for making newsprint is worth $12-15 per ton.

2) Clean, corrugated cardboard, worth $7-12 per ton. Of interest here is a recent conclusion by the National Academies of Engineering and Science: "There are no major technological limitations to the reuse of newsprint and paperboard."

3) Nearly all ferrous metals except "tin" cans (see below for a discussion of tin cans). The mining of the low grade iron ore taconite (25-30 per cent iron) over the past dozen years signals the scarcity of a high grade iron ore in the United States. Scrap iron is worth one cent per pound ($20 per ton), and junked cars are reclaimed in many cities for ferrous metals. However, the high capital cost of auto-shredding plants dictates that they be found only in the large urban centers that can provide a steady influx of junk cars. Clean Steel, Inc., for example, in Long Beach, California, shreds 500-800 cars daily. Although there presently exists a shredder suitable for automobile processing in Erie County, residents junk only 16,000 cars yearly, which would not be sufficient to economically justify the operation.

4) Aluminum, all forms, except possible "mixed" aluminum cans (can ends are steel). At 1966 prices of 12 to 13 cents per pound an aluminum salvage program was not economically self-sustaining. During mid-summer, 1970, Reynolds Aluminum stated publicly that scrap aluminum was worth $200 per ton (10 cents per pound) and paid 1/2 cent per aluminum can brought to their reclamation plants. Los Angeles collected more than a million aluminum cans per month to supply some 25 tons of aluminum for reclamation. The U.S. Reduction Company, East Chicago, Indiana, estimates that a city would have to supply from 50 to 500 tons of aluminum per month before it would be considered a good source of secondary aluminum.

Two factors, however, should make aluminum recycling economically more feasible than in the past: (a) an increasing amount of aluminum in municipal refuse (b) a more effective recovery of aluminum cans due to an increased degree of public awareness of the non-degradability of cans coupled with a greater public desire to cleanse the environment.

5) Rubber tires. In 1962, 16 percent (360,000 tons) of the rubber used for manufacture came from discarded tires. Each new tire (with a weight of about 20 pounds) contains 2-5 pounds of reclaimed rubber. (Oddly enough, government vehicles are required to have tires containing no reclaimed rubber). Reclaimed rubber is mechanically masticated more quickly than crude rubber and is well adapted to absorb fillers; other characteristics make it easier to work with than crude or synthetic rubber. The bead wire cannot be economically salvaged. A rubber reclaiming plant in St. Louis pays $14 per ton, although the price for old tires in Los Angeles is $6.50 less per ton because of their relative abundance.

6) Other Metals. Copper, even when surrounded with electrical insulation, seems worth saving with the present scrap price of 30-40 cents per pound. The copper alloy brass is worth 25-40 cents per pound and should, along with zinc and copper, be regarded as too valuable for burial in a landfill.

There are some solid waste components having little or no current value, which nevertheless, for the following reasons, should probably be reclaimed:

1) Current research points to a technological breakthrough that will provide a use for the component.
2) The component occurs in significant quantities in the solid waste stream.
3) The component is easily separated from other solid waste components.
4) The component as it occurs in the solid waste stream is comparatively uncontaminated or is easily cleaned.
5) The component is valuable in one section of the U.S. but not in another.

Components which fall into this category include:

1) Tin Cans. Municipal solid waste is about 5 percent "tin" cans by weight. Erie County's production of approximately 500 tons per day of municipal refuse* would therefore yield about 25 tons of tin cans per day. Cans from Los Angeles residents are separated magnetically at a landfill site, burned, shredded, and rail hauled to low-grade copper mining operations in the Southwest where they are worth $50 per ton. The high surface-area-to-weight ratio makes the shredded

*Source: "A Solid Wastes Management Plan for Erie County, Pa." Prepared by the Zurn Environmental Engineers for the local governmental agencies of Erie County, through the Board of the Erie County Commissioners.

cans an excellent source of iron for the precipation of copper from the copper sulfate leachate. East of the Mississippi there are no copper mines, and transportation costs make it unprofitable to haul cans farther than a few hundred miles. Nevertheless, the ease of separation (magnetic) and steady production of a significant tonnage of tin cans make saving them seem worthwhile.

2) Glass. In 1966, the U. S. packaging industry used some 50 percent more glass than steel and aluminum combined: about 8 million tons of glass compared to 5.4 million tons of steel and aluminum (5.2 million tons steel, 0.17 million tons aluminum). The graph on page 4 shows glass, ceramics, and ashes together making up some 8 percent of municipal waste. On this basis an estimated figure for the daily accumulation of glass from municipal waste in Erie County is 40 tons. Sixty to eighty percent of the glass in domestic wastes is from bottles of various types, ten to thirty percent is composed of broken window panes, and the remainder comes from TV tubes, fluorescent lamps, and cut glass.

The glass-making industry has regularly used from 10 to 60 percent of salvaged glass or cullet as a basic raw material (worth $15 a ton in 1967). About one half of the cullet comes from scrap dealers; the rest from bottlers or manufacturers who use glass in the making of their products. Salvaged glass must be free of contaminants, especially metals, and sorted according to color before it can be used as cullet. Domestic refuse glass is heterogeneous with respect to both color and composition. Current research also indicates that ground waste glass can be substituted for sand in aerated concrete or processed into glassphalt, both used in making road surfaces.

Inasmuch as the raw materials (sand, limestone, soda ash) used in glass manufacture are plentiful and cheap ($10-15 per ton), there is no easy market for salvaged glass. It appears, however, that uses will be developed to provide some kind of market for reclaimed glass in the near future.

3) Plastics. Over the past 10 years plastics have taken over packaging needs dominated for many decades by paper, glass, wood, and metal. In eight years, from 1958 to 1966, plastics in packaging increased from 333 million pounds to 1.8 billion pounds, an increase of 550 percent (cellophane is not a plastic and is not included in these figures). Although the total tonnage in plastics was only about 2 per cent of the

total 52 million tons of packaging materials in 1966, plastics accounted for about 10 percent of the dollar volume in packaging.

Municipal waste consists of about 1 percent plastics on a weight basis, but the fraction of plastics in landfills will increase over the years because of its near indestructability. Most plastic material does not degrade, disintegrate, or dissolve when left to the forces of nature.

The two main types of plastic, thermoplastics and thermo-setting plastics, are distinguished by their reaction to heat. The former may be reshaped by heat and pressure, while the latter, once formed, cannot be melted and remolded. All the large volume plastics are thermoplastics, and if these can be separated readily from the thermosets in municipal wastes, recycling may be appropriate. Current salvaging of plastics is limited to industrial and "in-house" reclamation of rejects, trimmings, etc., where the type is known and the material is uncontaminated. Reclaimed plastics from industrial salvage must be ground, melted, screened, blended, and pelletized before sale. There is not a favorable outlook for the extensive use of recycled plastics at the present time.

A brighter future seems more likely for plastics as raw material for pyrolysis (see Section IV). Union Carbide has patented products such as paste waxes, polishes, lubricants, and adhesives obtained from the pyrolysis of polyethylene resin. Pyrolysis breaks down plastic materials into a variety of simpler molecules, similar to those in crude petroleum. It seems reasonable to save waste plastic, not for recycling as plastic, but as a feedstock to be pyrolyzed into useful compounds. No demand for waste plastics for pyrolysis exists presently, but perfection of the technology is a near certainty, and subsequent consumption of waste plastic seems likely.

SECTION III: STATE OF TECHNOLOGY

As recycling has gained wide conceptual acceptance, technology has responded with a change in its approach to the solid waste problem from an emphasis on disposal to an emphasis on recovery. Nevertheless, as the balance begins to tip in favor of recovery, economic considerations have produced a continuum of treatment processes which combine recovery and disposal in nearly every measure. As development proceeds towards recovery, new processes must be introduced; and one of the most fruitful sources for these new processes is, of course, the technology already developed in other fields for materials handling. Thus, following N. L. Drobny, et. al. (8), we may identify three major areas of consideration in our technological review:

1) present processes used essentially for solid waste disposal;
2) present and proposed processes for solid waste recovery;
3) the material processing technology as developed in other fields.

Current disposal practice for municipal solid wastes follows one of three procedures: (1) sanitary landfill, (2) incineration, or (3) composting*. Two unit processes are common to these standard systems: densification and size reduction. In densification the weight of the material per unit volume is increased; scrap-metal baling is an example of such an operation. In size reduction individual particles of waste material are simply reduced in size. Rock crushers, mills, and sink-mounted garbage grinders are examples of standard equipment used to perform this operation.

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*See footnote and explanation for this categorization, page 16.

To date, most municipal solid wastes in the United States have been disposed of in landfills. Even after other disposal methods have been applied, a residue remains which must ultimately be disposed of by landfilling. For this reason, it appears that landfills will continue to be required to a certain degree in the future. The main unit process for landfilling is densification. The volume of the waste must obviously be reduced to maximize the use of available landfill capacity. In most sanitary landfills, crawler or rubber-tired bull-dozers have been used for this purpose. In the experimental landfill operation in Madison, Wisconsin, both densification and size reduction are employed. Municipal refuse is first milled by a vertical rotor multi-stage mill, then densification is applied at the landfill site by a compacting bull-dozer. The pre-landfill milling produces particulate material which is readily compacted in the landfill.

For disposal of solid wastes by incineration both densification and size reduction operations may be applied. Size reduction is generally used on bulky or oversized items in the municipal waste. Densification is necessary only if it is desired to produce a briquette-type fuel from the solid wastes. For such purposes, the refuse must be sorted to remove non-combustibles, ground for uniformity, and dried, as well as compacted. Studies conducted on such operations now being tested in Western Europe (33) show that one ton of incineratable briquettes with a calorific value of approximately 7,500 BTU per pound can be produced from six tons of normal refuse, leaving five tons to be disposed of by other means. Heat recovered from incinerators has been used to heat schools, offices, and houses, as well as to drive turbogenerators. Metal recovery from incinerators has also been developed (38, 24).

Composting, which has been practiced in Europe for many years, has not seen significant commercial success in the U. S., probably because the orientation of U. S. agriculture has been toward faster acting and more specific commercial fertilziers. Moreover, compost has difficulty meeting the precise chemical demands imposed by the highly productive and technical agriculture that exists in the United States.*

For composting, densification is not needed. Size reduction, which is usually desirable, may be effected by shredding the refuse before it goes into any process to produce compost. Size reduction processes differ from plant to plant. In some plants, which use can- and bottle-free input garbage, no salvage is necessary; and the total refuse is milled. In the Altoona (Pa.) Composting Plant (an experimental station of the Fairfield Engineering Company, see note 16), for example, the primary mill is a hammermill, which produces an average particle size of 0.75 inch. Ferrous particles are separated from the milled refuse by a magnetic drum separator, and the residue is converted into fine particle size pulp by a wet grinder. Other pre-composting separation methods may also be

*It is for this reason that we have presently placed composting under the methods for solid waste disposal, although an increased market for compost in the future would justify a reclassification of composting as a useful process for recovering solid wastes. The point, in any case, is academic.

applied for removing non-magnetic metallic particles and glass. In Europe, for example, hand separation is practiced for the removal of large sized paper, cardboard, rags, metals, and bottles. This material may then be converted to compost in a digester by the action of aerobic thermophilic bacteria, producing a weight reduction of approximately 30 per cent and a volume reduction of 80 per cent. The gray-black product that is produced in 3-5 days is practically odorless and attracts no insects or rodents.* The removal of shredded plastic (which is easily accomplished after digestion) gives a more homogenous product; drying and pelletizing produces B-B-sized particles with a carbon-to-nitrogen ratio of 20 to 1. Such material is useful as a soil conditioner, but is unsuitable for marketing as a fertilizer. The compost can be enriched through the addition of sewage sludge or animal wastes; numerous tests reveal that no pathogenic organisms survive the sustained heat (140-160° F.) of the digester process. The Metropolitan Waste Corporation in Houston, Texas (39, 42), was able to process 30 per cent (300 tons per day) of the total waste of Houston into compost, before it had to be closed down recently for lack of funds.

Processes which emphasize the recovery of solid wastes have so far been largely confined by their economic viability to dealing only with certain components of the wastes. So it is that individual industries have gone quite far toward regaining a specific usable input resource from variously constituted collections of solid waste, while the treatment of general, mixed waste to reclaim a variety of products has lagged behind.

*Source: Private Communication from Altoona FAM, Altoona, Pa.

The most thoroughly proven recycling operations to date are those which begin with wastes which never become a part of the general lump called mixed municipal solid wastes. Thus, while not immediately usable as input for manufactured items, they are already in a first approximation to purified form; and their consistency is qualitatively different from that given in the graph on page 4. Scrap cellulose, for example, available in such diverse forms as corrugated paper boxes, newspaper, magazine paper, brown paper, mail, paper food cartons, tissue paper, and wood, has long been reclaimed for making newsprint fiber, such as in the highly successful operation at the Garden State Paper Company in Pomona, California (17). Cellulose may also be used as fuel for the generation of energy, converted to compost (see pages 16-17, above), or introduced as raw material for pyrolysis units (see page 19, below). Scrap metal - brass, copper, aluminum, iron, steel, etc. - has for many years been a prime resource of the metals industries.

A few relatively new recycling operations begin with the mixed municipal solid wastes themselves. Three installations exist in the United States today which are significant from this point of view:

THE ALTOONA (PA.) COMPOSTING PLANT (16), mentioned above (page 16), successfully converts a major portion of municipal garbage to compost. (This may be justifiably called recovered waste; see note, page 16.)

THE BLACK CLAWSON COMPANY IN FRANKLIN, OHIO (2), has developed a pilot facility for the city of Franklin, which is an attempt to provide separation and recovery of cellulose fiber, ceramics, and certain metallic materials. This facility is being funded by the Office of Solid Waste Management Programs of the Environmental Protection Agency.

THE U. S. BUREAU OF MINES IN PITTSBURGH, PA., (35) AND IN COLLEGE PARK, MD. (6): Studies at the Pittsburgh Energy Research Center indicate that both municipal and industrial wastes can be pyrolyzed (heated in the absence of air) at 900° C to yield oils marketable as fuels or as sources of such chemicals as styrene; combustible hydrocarbon gases which can be used as fuel in the pyrolization plant itself; and carbon black. Studies in College Park are developing a process which aims to recover the mineral components from incinerator residues.

Four systems are in the design or proposal stage which also begin their operations with mixed solid wastes:

THE ALUMINUM ASSOCIATION OF NEW YORK, N.Y. (10), has designed an integrated municipal refuse recycling plant which combines the current incinerator and pyrolysis technology with the Bureau of Mines mineral recovery unit (6) to produce fiber, heat, and recovered mineral components.

COMBUSTION POWER, INC., IN MENLO PARK, CALIF. (11), has completed pilot plant studies and is proposing a full-scale plant for the conversion of municipal solid waste to electrical energy by means of a fluid bed combustion chamber feeding a gas turbine generator. Combustion Power is also being funded by the Environmental Protection Agency.

HERCULES, INC., IN WILMINGTON, DEL. (13), will utilize both the technology developed by the Fairfield Engineering Company, Marion, Ohio, for converting waste cellulose to compost (16), and the pyrolysis technology of the Bureau of Mines (35).

MONSANTO'S ENVIRO-CHEM SYSTEM IN ST. LOUIS, MO. (20), the so-called Landgard System, has been developed through a 35-ton-per-day pilot plant and is a completely integrated plant based on the Bureau of Mines pyrolysis technology.

Unfortunately, it is clear from the above that the output of recycling operations which begin with the mixed wastes does not in general meet the input requirements of those which deal with the refinement of selected waste components. The tentative links which have been established proceed, for example, from mixed solid waste to cellulose products, or from mixed solid waste to ferrous metal products. But much work remains to be done on the development of a comprehensive fractionator-classifier which can feed simultaneously into several different material-specific recycling systems. One such classifier that comes close to meeting these needs is an air classifier (see page 23, below), which will separate a uniformly-sized mixture into two components on the basis of different particle density, or a uniformly dense mixture into two components on the basis of different particle size. Another is the system being developed by Black Clawson in Franklin, Ohio (2), which has, in effect, placed a number of different single-component sorting mechanisms under one roof, to finally obtain from the mixed wastes several different components suitable for input as industrial raw material.

It still remains true, however, that the widest technological gap in an economically feasible conversion of mixed municipal solid wastes to usable resources is precisely at the point of primary, comprehensive classification. It was toward developing such a classifier, with large capacity and broad capability, that the Erie County Health Department directed its attention.

At an early stage of its exploratory work into the technology of material processing in other fields, the GLRI research team recognized the potential significance of mining techniques applied to solid waste extraction. Indeed, once the analogy is made, it is difficult to understand that it was ever ignored:

Solid waste might well be considered an impure ore, which must be mined and refined (i.e., recycled) before it can be used as raw material for manufacturing. And solid waste recycling, like mining, will always be a matter of separating the desired materials to some statistically approximate degree of refinement, to produce a material salable for maximum profit at an overall minimum cost. From exhaustive sourcebooks on mining technology (4) numerous methods of ore separation and refinement which might also be applied to solid wastes have been identified. These methods are based on inherent or induced differences in the physical properties of the components of the solid mixture. The major variable properties of the components which may be exploited in separation processes are color, luster, size, shape, strength, brittleness, structure, texture, surface characteristics, specific gravity, magnetic susceptibility, electrical conductivity, radioactivity, and susceptibility to decomposition by the action of various agents. These properties of individual components may also be changed to varying extents by physical and chemical treatments such as drying, oxidation, and the like. Applicable separation methods are as follows:

Crushing

Crushing is normally done in two or three stages, depending upon the reduction necessary to attain grinding-mill feed-size and upon the capacity of the crusher. Jaw and gyratory crushers are the usual primaries. Metallic ores are, in general, too hard for other types. Various gyratory and cone-type crushers are almost universally found as secondaries. Hammermills are also used as secondary crushers for rocks ranging in hardness from soft limestones to clay, but they can as well crush harder rocks for concrete aggregates.

Grinding

Grinding is the final stage in size reduction; the grinder must reduce material to a limiting size. The most economical way to grind rock is to rub it in a thin layer between hard surfaces, under pressure sufficient for cracking.

Screening

Screening is a separating process primarily based on particle size. Screening efficiency is measured in two general ways: One method compares the proportion of over-sized material that will pass through a given operating screen, with the proportion of the same material from some dried standard test lot that will pass through a test screen of the same aperture. Alternatively the comparisons are made on proportions of undersized material. Commercial screens are classified by their respective methods of effecting relative motion between the feed bed and the screening surface, as follows: (a) Fixed Screens, (b) Revolving Screens, (c) Shaking Screens, and (d) Vibrating Screens.

Fluid Classification

In fluid classification separations are effected by the colinear opposition to gravity of drag forces produced on a particle by its relative motion through a fluid. Settling velocities (positive or negative) are a function of size, shape, and specific gravity. One typical design for fluid classification incorporates a cylindrical tube, or sorting column, through which particles fall relative to a rising current of water. Whether the particles fall or rise relative to the column wall depends upon the parameters of the individual particles and on the rising velocity of the water. Another, more recent design is the Air Classifier developed by the Stanford Research Institute (1), which separates particles on the basis of density by dropping them through a horizontal crosscurrent of air (see page 20).

Fluid - Solid Separation

For the separation of fluids from solids, filters and dust collectors may be employed. Filtration performs separation by causing the fluids to pass through a finely perforated septum that will not pass the solids. Essentially this is ultrafine screening. As in screening, friction is the principal force resisting passage. The driving force may be gravity, but usually it is a differential fluid pressure on the two sides of the separating filter. Vacuum filters are generally used in handling wet pulps, while dry filters are employed in dust collection. Centrifuges and cyclones may also be applied to fluid-solid separation.

Washing and Scrubbing

Washing and scrubbing are used to remove minor, fine constituents from the main particles, so that the latter may be accurately sorted.

Sorting

Both hand sorting and mechanical sorting may be used on solid waste, although hand sorting was abandoned years ago in the mining industry. In either case, the materials must be loose and clean enough to be picked out according to the given distinguishing property. For this reason, crushing, grinding, screening, fluid classification, and washing may all be necessary prior to the sorting. Mining technology has a variety of specialized mechanical sorters or pickers which may find application in solid waste recovery, including:

1) The Spiral Picker, used for separating anthracite from flat slate;

2) Slotted - Screen Pickers, used for separating anthracite from flat slate and middlings;

3) Ziegler Pickers, used for separating flat slate from rounded particles;

4) The Ayers Picker, also used for separating flat slate from rounded particles.

Mechanical sorters utilizing color or radioactivity have recently been introduced. Color differences or radioactivity is detected by a sensing device, which may operate an air blast to move a particle to a desired location.

Gravity Concentration

Separation of material according to specific gravity may be accomplished by jigging*, tabling*, spiralling*, and heavy media separation, as well as by fluid classification (see pages 22-23, above).

*Mining terminology

Magnetic Separation

Magnetic separation can be employed dry or wet, and it is the most effective separation method for ferrous materials. A mixture of particles which respond differentially to a magnetic field is introduced into the field so that all the particles are equally subjected to the field and to another force or forces, such as gravity, friction, inertia, centrifugal forces, or fluid resistances, directed at an angle to the magnetic field. Pulley- or drum-type magnets are used for relatively coarse feeds of highly magnetic materials. Weakly magnetic materials, on the other hand, require high intensity machines and slow, even feed rates to attain the small airgap necessary for separation. Non-magnetic and weakly magnetic minerals containing iron can be separated by a magnetic drum, but in such cases particle diameters should be less than 3/4 inch.

Electrostatic Separation

Electrostatic separation depends upon differences among minerals in the mobilities of their free electrons when the mineral particles are in an electric field. Materials are classified electrostatically as conductors (high electron mobility), insulators, or dielectrics (low electron mobility), or semiconductors (much higher electron mobility than the dielectrics, but materially less than that for the conductors). Within each of these categories there is a range in the electron mobilities of various materials; but, for separating applications, this range is sufficient only for the dielectrics. Minerals are conductors, while most other materials are dielectrics. Because of the direct relationship between field force and particle volume, the larger particles of a given mineral deviate more than do the smaller; and a rough sizing can be obtained. The application of electrostatic separation is presently limited to particles passed by 10- to 150-mesh screens.

Flotation

Flotation is a process for rendering a mixture of finely ground minerals (capable of passing through a 20-mesh screen) susceptible to gravitational separation. This is done by inducing selective attachment of gas bubbles to one mineral species while the mixture is submerged in water. Although, theoretically, there is no limit to the number of different kinds of minerals that can be separated by flotation, experimentation has proved that the only naturally flotable minerals are the solid hydrocarbons. Air bubbles adhere to clean surfaces of these minerals in pure water. When bubbles adhere to other minerals in water, organic contamination of the particle surfaces is positively indicated. The minerals that can be coated with pure hydrocarbon oil in water are hydrocarbon minerals such as coal, sulphur, graphite, and a group of sulphides. Although flotation is quite complex in operation, it is one of the most modern, efficient, and widely applicable methods of separation.

Having taken the preceeding account into consideration, the GLRI research team (see Introduction, Section I) proposed the incorporation of some of the above elements into the design of a pilot plant for the study of the comprehensive fractionation of municipal solid wastes. The major innovation and key feature of this design is the primary, or Bowerman Classifier, so named in honor of Frank R. Bowerman, the member of the study team who contributed the design. The output material from this fluid classification process can serve as input material to fiber, metal and glass recovery, composting, energy production, and pyrolysis systems. Thus, this output will be compatible with the significant other proposed pilot facilities in the nation.

SECTION IV: THEORETICAL CONSIDERATIONS

The Bowerman Classifier makes use of a physical phenomenon described by Stoke's Law. This law states that particles having the same size and shape but different densities will have different settling velocities according to these densities while falling through a quiescent fluid. The principle may be extended to particles falling through a fluid flowing with a low velocity. Therefore, particles of similar size and shape falling through a fluid flowing at low velocity in a settling tank will be deposited on the bottom in different locations. All other factors remaining constant, this scattering of the settled particles will be governed by the densities of the particles and by the velocity and the density of the flowing fluid.

A more precise technical analysis follows.

In falling freely through a quiescent fluid, a particle accelerates until the frictional resistance, or drag, of the fluid equals the impelling force acting upon the particle. Thereafter, the particle settles at a uniform rate.

The impelling force is equal to the effective weight of the particle, i.e., its weight in the suspending fluid.

Therefore,

$$F_I = (\rho_s - \rho)\, gV, \qquad (1)$$

where F_I is the impelling force, g the gravity constant, V the volume of the particle, and ρ_s and ρ are respectively the mass density of the particle and fluid.

The drag force F_D of the fluid, on the other hand, is a function of the dynamic viscosity μ and mass density ρ of the fluid and of the velocity V_s and a characteristic diameter d of the particle. To be fully representative, this diameter must reflect (1) the orientation of the particle with respect to the direction of its motion, represented, for example, by the area of the projection of the particle cross-section onto a plane at right angles to the direction of the particle motion, and (2) the relative frictional surface of the particle in contact with the fluid represented, for example, by its surface area in relation to its volume. Dimensionally, therefore, $F_D = \phi(v_s, d, \rho, \mu)$ or, designating dimensional relations by square brackets,

$$[F_D] = [v_s^x d^y \rho^p \mu^q].$$

Introducing the fundamental units of mass m, length ℓ, and time t, of the various parameters into this equation,

$$[m\ell t^{-2}] = [m^{p+q} \ell^{x+y-3p-q} t^{-x-q}],$$

and solving for x, y, and p in terms of q,

$$F_D = v_s^2 d^2 \rho\phi(v_s d\rho/\mu) = v_s^2 d^2 q\phi(R), \qquad (2)$$

where R is the Reynolds number. This dimensionally derived relationship for the frictional drag has been verified experimentally.

By substituting the cross-sectional, or projected, area A_c at right angles to the direction of settling for d^2, the dynamic pressure $\rho v_s^2/2$ for ρv_s^2, and Newton's drag coefficient C_D for $\phi(R)$,

$$F_D = C_D A_c \rho v_s^2/2. \qquad (3)$$

The magnitude of C_D is not constant, but varies with R.

Equations (1) and (3) can now be combined to establish a general relationship for the settling or rising of free and discrete particles, as follows:

$$(\rho_s - \rho) g V = C_D A_c \rho v_s^2/2,$$

or,

$$v_s = \left[\frac{2g}{C_D} \cdot \frac{\rho_s - \rho}{\rho} \cdot \frac{V}{A_c} \right]^{1/2}. \qquad (4)$$

Thus, for spheres,

$$V = \pi d^3/6 \text{ and } A_c = \pi d^2/4,$$

so that

$$v_s = \left[\frac{4}{3} \cdot \frac{g}{C_D} \cdot \frac{\rho_s - \rho}{\rho} \cdot d \right]^{1/2}. \qquad (5)$$

For eddying resistance at high Reynolds numbers ($R = 10^3$ to 10^5), C_D becomes practically constant with values of 0.4 or 0.5 over wide domains of R,* and

$$v_s = \left[\frac{4}{3} \cdot \frac{g}{0.4} \cdot \frac{\rho_s - \rho}{\rho} \cdot d \right]^{1/2}, \qquad (6)$$

or,

$$v_s = \left[\frac{4}{3} \cdot \frac{g}{0.5} \cdot \frac{\rho_s - \rho}{\rho} \cdot d \right]^{1/2}. \qquad (7)$$

---

*Zahm, A.F., and Roshko, A. "Experiments on the Flow Past a Circular Cylinder at Very High Reynolds Number." Jour. Fl. Mech., Vol. 10 (1961), p. 345.

For viscous resistance at low Reynolds numbers (R <0.5),

$C_D = 24/R$, and

$$v_s = \frac{g}{18} \left(\frac{\rho_s - \rho}{\mu}\right) d^2 . \qquad (8)$$

Equation 8 is the Stoke's law.

For particles having same size and shape, but different mass densities, falling through the same fluid flowing at a uniform velocity, the terms C_D, V and A_C in Equation (4) will be constant and it reduces to

$$v_s = K.\left(\frac{\rho_s - \rho}{\rho}\right)^{1/2} \qquad (9)$$

where,

$$K = \left(\frac{2g}{C_D} \cdot \frac{V}{A_C}\right)^{1/2} = \text{constant.}$$

Therefore, two particles of same size and shape having different densities will have different settling velocities and their interrelationships may be represented by the following expression

$$\frac{v_{s1}}{v_{s2}} = \frac{(\rho_{s1} - \rho)^{1/2}}{(\rho_{s2} - \rho)^{1/2}} \qquad (10)$$

where, v_{s1} and v_{s2} are the settling velocities of particles having densities ρ_{s1} and ρ_{s2}, respectively.

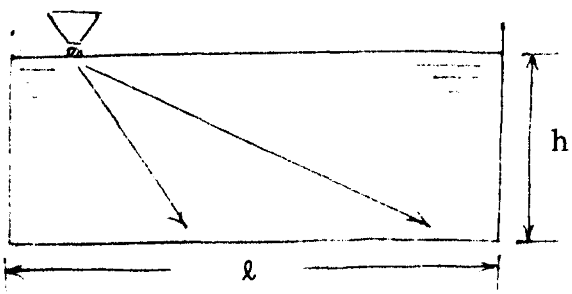


Figure 1

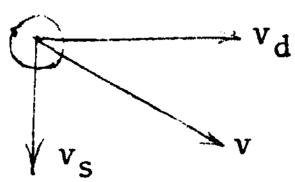


Figure 2

The paths taken by discrete particles of same size and shape but different densities, settling in a horizontal-flow basin are shown in Figure 1. They are determined by the vector sums of the settling velocity v_s of the particle and the displacement velocity v_d of the fluid in the basin as shown on the free body diagram in Figure 2.

Settling time of the particle

$$t = \frac{h}{v_s} \tag{11}$$

The horizontal distance travelled by the particle in this time,

$$S = t \times v_d \tag{12}$$

$$= h \times \frac{v_d}{v_s} \tag{13}$$

for any flowing fluid with uniform velocity of flow in the settling basin, both v_d and h are constant, and, therefore,

$$S = K'/v_s, \text{ where } K' = hv_d. \tag{14}$$

Hence,

$$\frac{S_1}{S_2} = \frac{v_{s2}}{v_{s1}} = \frac{(\rho_{s2} - \rho)^{1/2}}{(\rho_{s1} - \rho)^{1/2}} \tag{15}$$

where, s1 and s2 are the horizontal distances traversed by two particles of same size and shape having densities ρ_{s1} and ρ_{s2}, respectively in a fluid of density ρ.

The distance s may be increased by increasing either the depth of the settling basin h or the velocity of the fluid flow, v_d. But, for ideal settling basin (where all the particles are arrested within the basin) $v_d \lesssim v_s$. Therefore, s should be manipulated mainly by h, whereas v_d should be controlled by the minimum of the v_s, and settling basins with greater depth are expected to give a better scatter of the particles of same size and shape but having different densities.

SAMPLE CALCULATION

Let us assume that the municipal solid wastes have been crushed, shaped, and separated into uniform spheres of 2-inch diameter and allowed to drop into a rectangular settling tank with dimensions 20' x 5' x 5' deep. The fluid in the tank is water at 20° C, which has a density of 62.4 lbs./ft.^{3} and a kinematic viscosity of 1.0105 x 10^{-2} cm^2/sec., and which we assume is moving with a displacement velocity of 2 ft/sec. Let us further assume the induced particles move together with the water, i.e., there is no relative motion of the particles and the water in the direction of current flow.* Selected components of solid wastes and their densities are given in Table I.

TABLE I

Densities of Selected Components of Solid Waste

Component	Density in lbs/ft.^{3}
Glass	125
Paper	44-75
Ferrous Metal	488
Brass & Copper	532
Aluminum	169
Plastic	56-100

*This is an experimentally valid simplification, since acceleration of the particles to the velocity of the current takes place in a very small fraction of a second (see A. F. Taggart, "Sedimentation Method of Mining," in Reference 4-a).

SOLUTION

The Reynolds number, $R = \frac{v_s \cdot d}{\nu}$.

Here d = 2 inches = 2 x 2.5 = 5 cm.

$\nu = 1.0105 \times 10^{-2}$ cm^2/sec.

For high Reynolds numbers (see page 31) C_D for spheres becomes practically constant with a value of

$C_D = 0.4$ for R = 2,000 to 10,000, and

$C_D = 0.5$ for R = 20,000 to 200,000.

For these Reynolds numbers, the corresponding limit velocities would be given by $v_s = \frac{\nu . R}{d}$, so that

for $C_D = 0.4$,

v_s = 4.04 cm/sec = 0.135 ft/sec to 20.21 cm/sec = 0.675 ft/sec;

for $C_D = 0.5$,

v_s = 40.4 cm/sec = 1.35 ft/sec to 404 cm/sec = 13.5 ft/sec.

The settling velocity for the particles of any one of the components may be calculated from Equations (6) and (7), while the settling velocities for the particles of other components may be found out utilizing the relationship shown in Equation (10).

Let us find out the settling velocity for glass. By iterative examination one may observe that $C_D = 0.5$ should be used, and

$$v_s \text{ (glass)} = [\frac{4}{3} \times \frac{32.2}{0.5} \times \frac{125 - 62.4}{62.4} \times \frac{2}{12}]^{1/2} \simeq 3.8 \text{ ft/sec}$$

To get a better scatter, let us assume a depth of 10 ft. for the tank instead of 5 ft.

The time taken by the glass particles to reach the bottom of the tank is

$$t_g = \frac{10}{3.8} \simeq 2.63 \text{ sec.}$$

The horizontal distance traversed by these glass particles in time t_g in a fluid moving at 2 ft/sec. is

$$S_g = 2.63 \times 2 = 5.26 \text{ ft.}$$

The horizontal distances traversed by particles of other solid waste components may be obtained from Equation (15).

DISTANCES TRAVERSED BY PARTICLES OF OTHER DENSITIES

PAPER (most dense): $5.26 \times [\frac{125-62.4}{75-62.4}]^{1/2} = 11.75$ ft.

FERROUS METAL: $5.26 \times [\frac{125-62.4}{488-62.4}]^{1/2} = 2.02$ ft.

BRASS, COPPER: $5.26 \times [\frac{125-62.4}{532-62.4}]^{1/2} = 1.92$ ft.

ALUMINUM: $5.26 \times [\frac{125-62.4}{169-62.4}]^{1/2} = 4.04$ ft.

PLASTICS (most dense): $5.26 \times [\frac{125-62.4}{100-62.4}]^{1/2} = 6.80$ ft.

Simple sedimentation rate studies were conducted and indicate that the shape factor is indeed significant (34). Particles of various density and configuration, as described in the table and notes below were introduced into a glass tube 45 inches (= 3.75 feet) high and 1-1/2 inches in diameter, containing approximately one quart of water. Their settling times t_s, in seconds, are given in Table II (25).

TABLE II

	lead[2]	zinc[3]	tin[4]	aluminum[5]	glass[6]
Flat (20 x 20 mm)	7	17	43	36	-
Spherical	2	no data	2	3	3
Crumbled Sheet[1]	2	4	6	6	-
Ribbon Twisted (7 x 50 mm)	4	5	31	36	-

[1] 20 x 20 mm piece crumbled for all trials

[2] lead sheet 8/1000 inches thick

[3] zinc sheet 6/1000 inches thick

[4] tin foil 1/2000 inches thick

[5] aluminum sheet 5/1000 inches thick

[6] 4-mm spheres weighing 0.092 grams each

By utilizing the preceeding data, the distances traversed by these particles in a settling tank of depth h with current velocity V may be computed from the following formula:

$$S = \left(\frac{ht_s}{3.75}\right)(V) \qquad (16)$$

Here S is the distance in feet. This is clear, since the settling time from any height is just

$$\frac{h}{v_s} = \frac{h}{3.75/t_s} = ht_s/3.75,$$

where v_s is the settling velocity (assumed constant).

Thus for example, in a settling tank 10 feet deep with a current velocity of 2 ft/sec, the particles in Table II would traverse the following distances (in feet):

	lead	zinc	tin	aluminum	glass
Flat	37.4	91	230	192	-
Spherical	10.7	no data	10.7	160	160
Crumbled Sheet	10.7	21.2	32	32	-
Ribbon Twisted	21.2	26.6	165.4	192	-

The preceeding mathematical analysis, as well as the calculations based on the preliminary experimental work described above, indicate that:

1) The proposed Bowerman Fluid Classifier will work to effectively separate organic from heavier inorganic fractions. Depending on the sizing operations that can be developed, the fractionation of the heavy fractions on the bottom of the classifier will be more or less efficient. It may be difficult, however, to separate the ferrous and brass & copper from each other due to their close densities. It was decided, therefore, that a subsystem would be needed for completion of the fractionation of the heavy residue (i.e., magnetic separation of the ferrous metal, etc.).

2) The tank length must be quite large to allow the paper particles to get settled. Paper and plastic particles should be allowed to flow out from the tank with the effluent and separated from water by screening.

3) Particles spherical in shape traverse similar horizontal distances and settle in similar stations if they are of similar densities. Particles other than sperical in shape traverse dissimilar horizontal distances whatever their densities, and settling stations overlap. Although it is not possible to reduce solid wastes into perfect and uniform spheres, the minimizing of flat shapes and the sieving of particles into size categories would reduce the "drag" effects on flat shapes to a minimum.

SECTION V: SCHEMATIC DIAGRAMS OF PROTOTYPE PLANT OPERATION

This section is intended to give the general reader a reasonably thorough, though unmathematical description of the possible operation of the various components of the proposed pilot plant, making use of the theoretical considerations outlined above. What follows should in no case be construed as an engineering diagram from which to build, or even as a finalized guideline from which these engineering specifications might be directly developed. Indeed the description does not necessarily represent all our latest thinking on details of the operation, though many specifics which are here included would undoubtedly find their way into a final design. Nevertheless, these schematics do incorporate our general, fundamental conceptions of what we intend to do and how we intend to go about doing it. When we become less than specific, it is invariably because the technology of the system is not completely understood--obviously, the entire rationale for a prototype plant stage would be removed if this were not the case. What we do build in now is a large measure of flexibility, and it is our desire to make this flexibility a meaningful building block that has motivated us to identify the form it takes at every turn.

The careful reader will note from comparison of the schematics with other sections (VI and VII) of this report that we have not always allowed our continuing thinking to be constrained by complete consistency of detail. Indeed, such constraint would be most unwise and misleading at a point when no component of the design can be considered final. Thus, for example, a "scalping" step has been schematized (Plate 3) and added to the operational flow chart (Plate 1), which is not provided for in the plan on page 75. This sorting of the largest and smallest objects of refuse may prove to be a desirable first operation, or it may turn out to be redundant. So with the variable-speed pump as specified on page 70: the hydraulic schematic of the Bowerman Classifier in this section (Plate 8) proposes an alternative solution to the problem of providing for different current velocities in the Classifier tank (see Plate 7). One of these systems may suffice by itself, or it may be the most effective scheme will incorporate both systems in tandem. A number of different sieving methods have been proposed (compare Step II in this section and the diagram on page 75). Finally, all these variations imply a multitude of possibilities for the final setup configuration of the pilot plant as a whole. Plate 2 furnishes one possibility; pages 75-76 provide another.

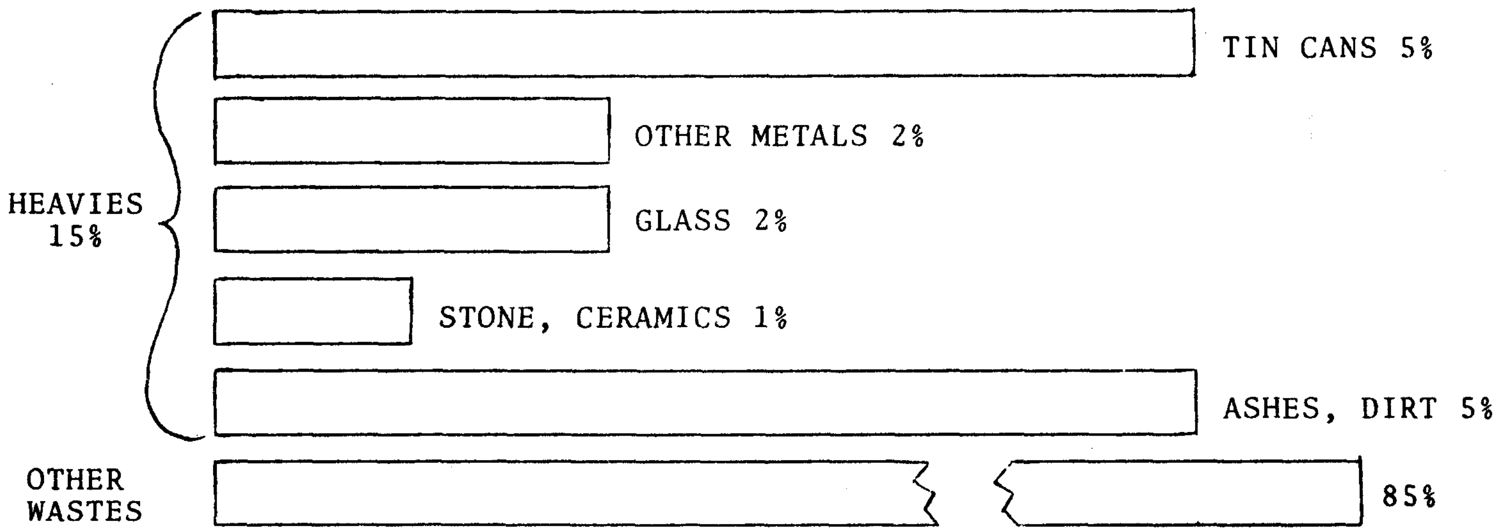
The reader is encouraged to follow the flow diagram (Plate 1) as the exposition proceeds and refer to the tentative floor plan (Plate 2) for a general understanding of how this sequence might be set up. The general account given here is followed by a more complete, step-by-step series of diagrams showing the components of the pilot plant as they will function in operation.

It has been noted above (Section IV) that solid waste particles must be carefully sorted with respect to size and given an approximately spherical configuration, before the Classifier can be expected to perform well-defined segregations based on density. In the prototype plant this may be carried out in up to four different preliminary steps. Most particles of the raw, mixed refuse are first introduced into a trommelling device (Step I, Scalping) where they are roughly segmented into three size-categories. Particles in the two largest size-categories proceed to a grinder (Step II), where they are ground small enough to join the smallest particles from Step I for more precise sizing in a vibratory screen (Step III, Sieving). The very largest particles entering the prototype plant, such as automobile tires, will initially be fed directly to the grinder; and this grinder output will then move on with the rest of the wastes to the vibratory screen. This sieving step produces a second output branching. The largest particles return to the grinder (Step II), while most of the others continue to a shaping mill (Step IV). Since, however, the tolerances of variations from spherical shape permitted by the Bowerman Classifier are not precisely known, some sieved particles may skip directly to the Classifier instead of going through the shaping mill. Particles which are shaped in the mill may require a second sizing in the vibratory screen before moving on to the Classifier (Step V).

Before the particles are introduced into the Classifier, the flow speed of the tank fluid is checked by introducing colored dyes or, perhaps, merely floating wood chips. Particles of roughly homogeneous size are then placed at the top of one end of the tank and allowed to settle to the bottom while being carried along by the current. Materials of different density--except those too light or too fine to sink into the fluid--settle along the bottom in different locations. Some of the particles carried beyond the tank area by the current may be deposited in subsequent runs of the Classifier at lower tank-fluid velocity.

A post-Classifier step is included in the pilot plant for further sorting of high density "heavy" material (Step VI, Heavy-Fraction Subsystem). Particles collected from the end of the Classifier tank nearest the input (see graph below) are sent to a subsystem designed by the ERIEZ Magnetics Corp., which will separate the input material into quantities of ferrous metals and nonferrous metals, and two different-density groups of nonmetallic substances.

HEAVY FRACTION
(Percentages of mixed, municipal solid waste by weight) (18)



Although the individual principles of operation have been proved in other applications and configurations, this step is an integral and legitimate part of the pilot plant both for its novel configuration of the components to provide great flexibility of adjustment for handling a wide range of experimental input material, and for its demonstration value as one of many subsequent refinement operations which may proceed after the initial separations of the Bowerman Classifier.

A few final observations are necessary before we commence with a closer look at each of these steps. First of all, while each of the basic components of the essential equipment is listed and briefly described in the schematics, we make no attempt to show such auxiliary equipment as electrical switch gear, power supply, water supply, drainage, lighting, ventilation, safety protection and the like. Such installations must, of course, be taken into careful consideration in the final engineering specifications for the pilot project.

Secondly, each of the modules in the flow diagram (Plate 1) must not be thought of as a unique and nonrepeatable step, but rather as a schematic step which may in practice represent a multiple series and/or parallel application of the step. This applies especially to the Bowerman Classifier, which, on account of its many variably-controlled parameters, may be used to produce output material with a number of different characteristics. Thus, for example, particles dropping into the basket nearest the input conveyor on the first run might be fanned across the entire tank bottom on a second run merely by increasing the fluid velocity in the tank. Or, the Classifier might be run with fluids which would impart special useful properties to the output material. If, for example, the Classifier tank was filled with a fuel oil such as kerosene, separated paper, plastics, and fiber would have uniquely beneficiated properties as slurried fuel, due to their immersion in the liquid.* Bottles, cans, and other metals collected

* This may also be accomplished by spraying the fuel oil onto the material on the traveling screen with the shower pump.

from the same tank might be run through a rotary kiln furnace, where the oil wetting their surfaces would probably provide sufficient fuel to burn off labels, burn out liquid or solid residues in the containers, and make the reclamation of steel by magnetic separation or aluminum by ballistic separation from the glass a more feasible procedure. Similarly, the use of a nonexplosive solvent such as trichloroethylene as either tank fluid or liquid spray at the traveling screen (see Step V, page 57) would degrease the collected paper and thus make it more amenable to reuse in reconstituted newsprint or in other improved paper products. The vast array of fluids having widely varying specific gravities, viscosities, and other properties makes for a great potential for studying unique applications of the Classifier to many different kinds of solid wastes.

Since the operation of the prototype plant is in all cases intermittent rather than continuous, analysis and re-evaluation may be made at each step; and any of the above measures may be tested. The more detailed flow diagrams of each step follow.

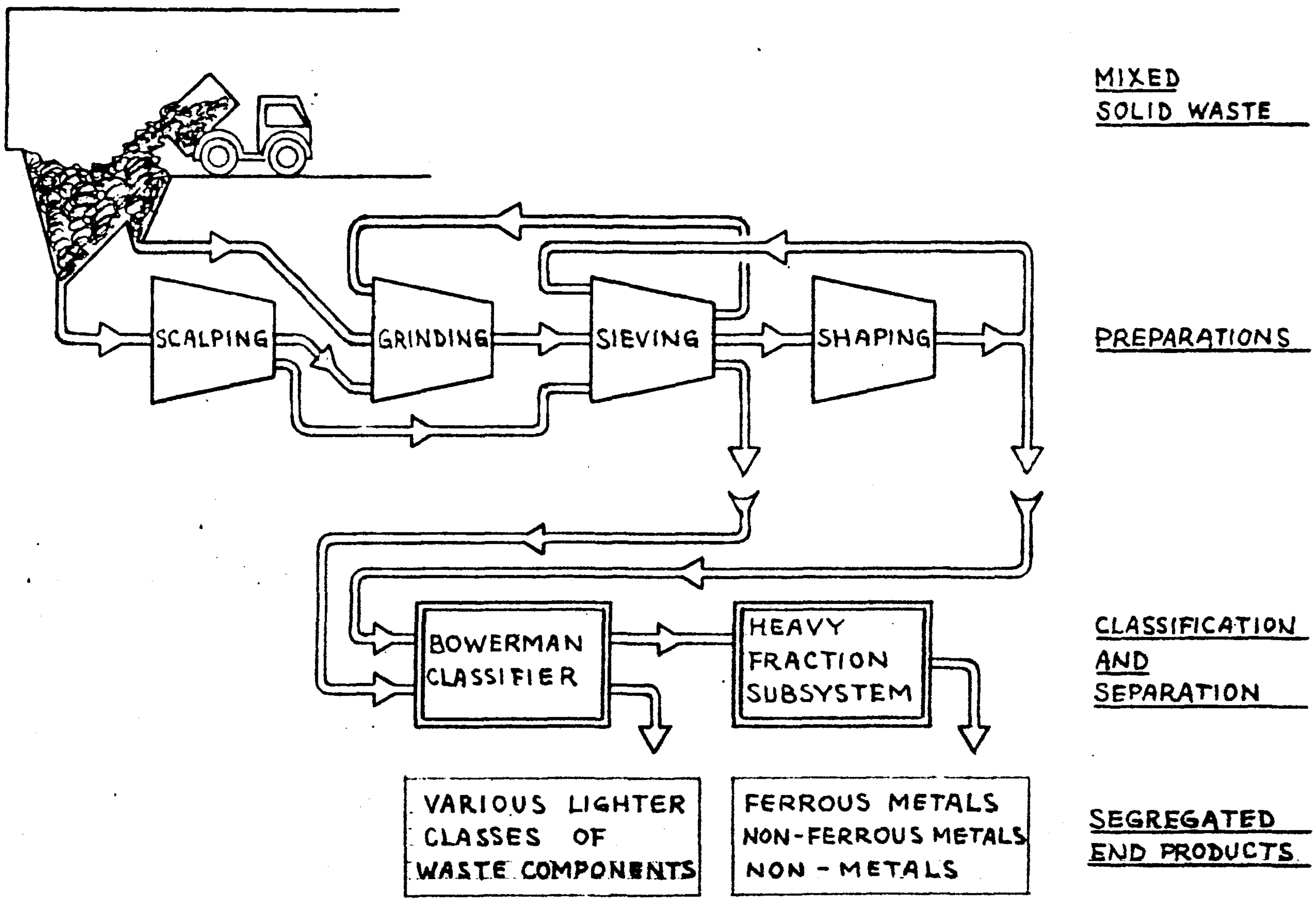
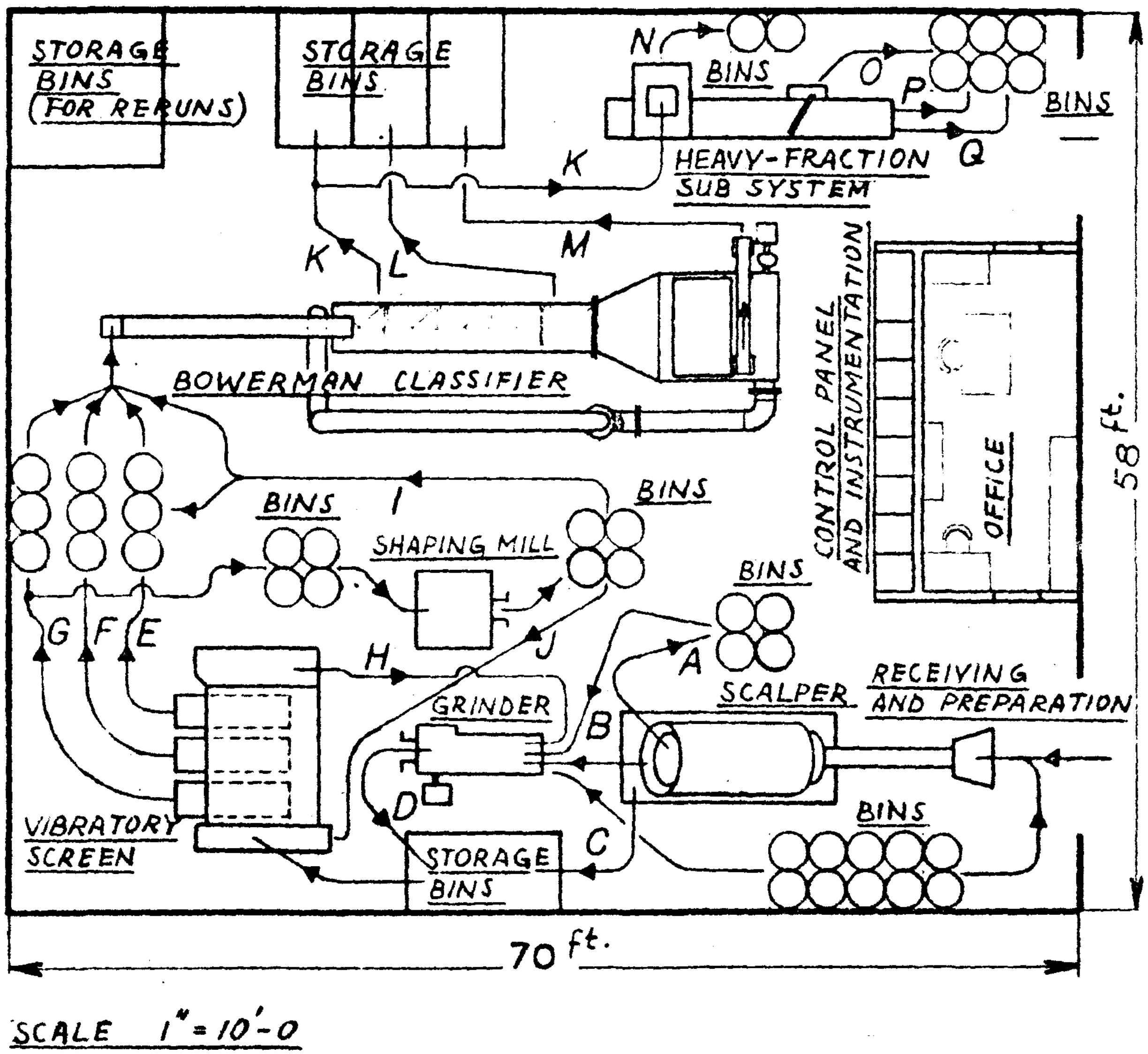


PLATE I | SOLID WASTE PILOT PLANT | FLOW DIAGRAM



PLANT FLOW SCHEMATIC
(Compare Plate 1)

1. Scalper
   A. Largest particles
   B. Middle-sized particles
   C. Fine particles

2. Grinder
   D. Ground particles

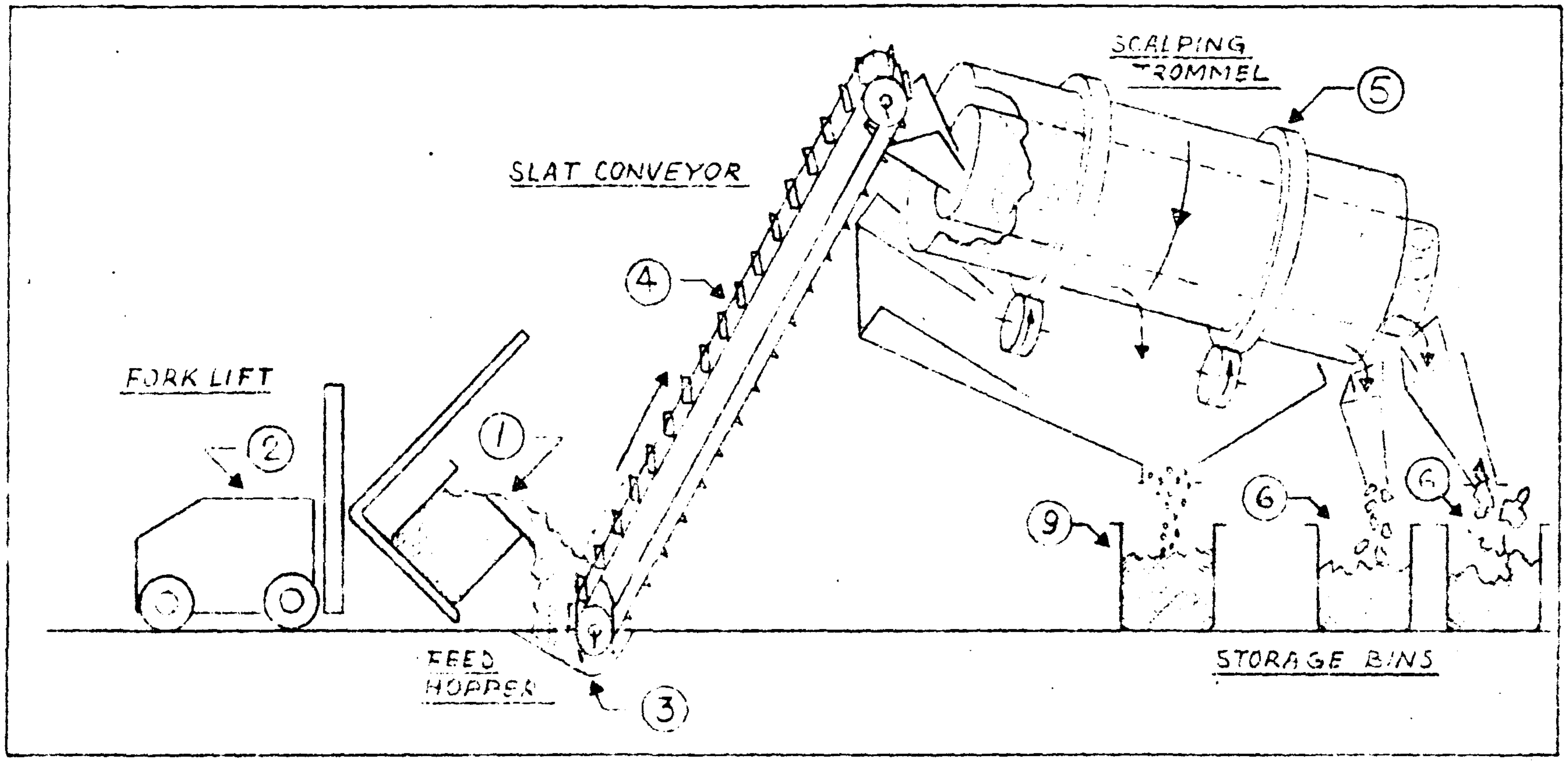
3. Vibratory screen
   E. No. 1 sized particles
   F. No. 2 sized particles
   G. No. 3 sized particles
   H. Oversized particles

4. Shaping mill
   I. Shaped particles ready for Classifier
   J. Shaped particles needing resizing

5. Bowerman Classifier
   K. High-density particles
   L. Low-density particles
   M. Particles from traveling screen

6. Heavy-fraction Subsystem
   N. Ferrous metals
   O. Nonferrous metals
   P. Heavy nonmetals
   Q. Light nonmetals

PLATE 2 | SOLID WASTE PILOT PLANT | FLOOR PLAN



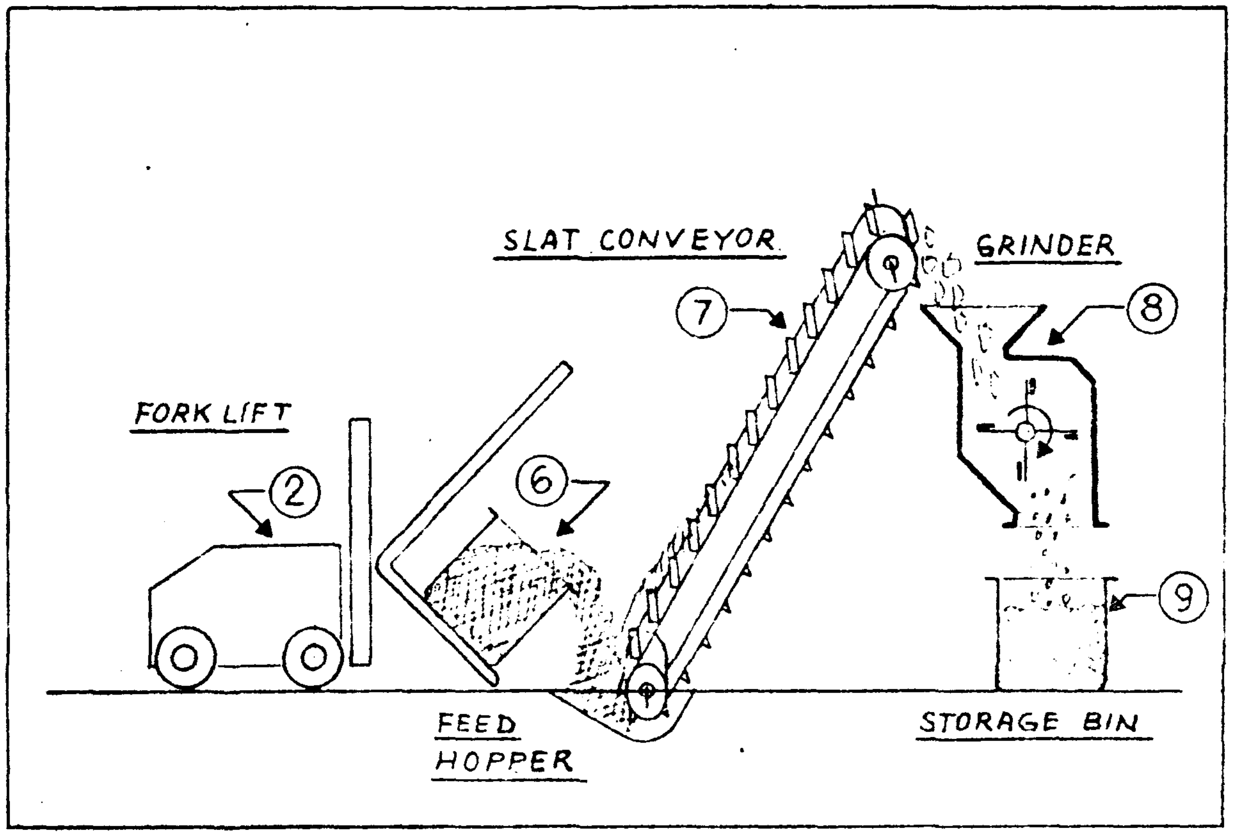
1. 30- or 40- gallon drums
2. General-purpose forklift
3. Feed hopper
4. Feed conveyor with drive
5. Trommel and drive
6. Storage bins for grinding (See Step II)
9. Storage bins for sieving (See Step III)

PLATE 3	SOLID WASTE PILOT PLANT	SCALPING

STEP I: SCALPING - PLATE 3 ABOVE

The mixed solid wastes are collected in the usual manner by a city or county agency and stored at the pilot plant in covered 30- to 40-gallon drums (1). For certain experimental purposes it may be desirable to preseparate such waste components as steel cans, aluminum cans, glass, plastic, and paper by hand; but the bulk of the pilot operation will preclude such action on the grounds that the input should simulate wastes as they would be received from municipal collecting vehicles.

A general-purpose forklift (2) conveys the drums to a hopper (3), from where they are fed by conveyor (4) to a trommel (5). The trommel will probably consist of two concentric drums rotating on an inclined axis. Material is fed into the inner drum, which is pierced with holes large enough to allow all but the largest particles of waste to fall through to the outer drum. Smaller holes on the outer drum allow particles below a certain size to pass to a chute, from where they are stored in bins (9) for immediate passage to Step III, Sieving. These large- and middle-sized particle segments, which reach only the inner or the outer drum, are stored in bins (6) for grinding.

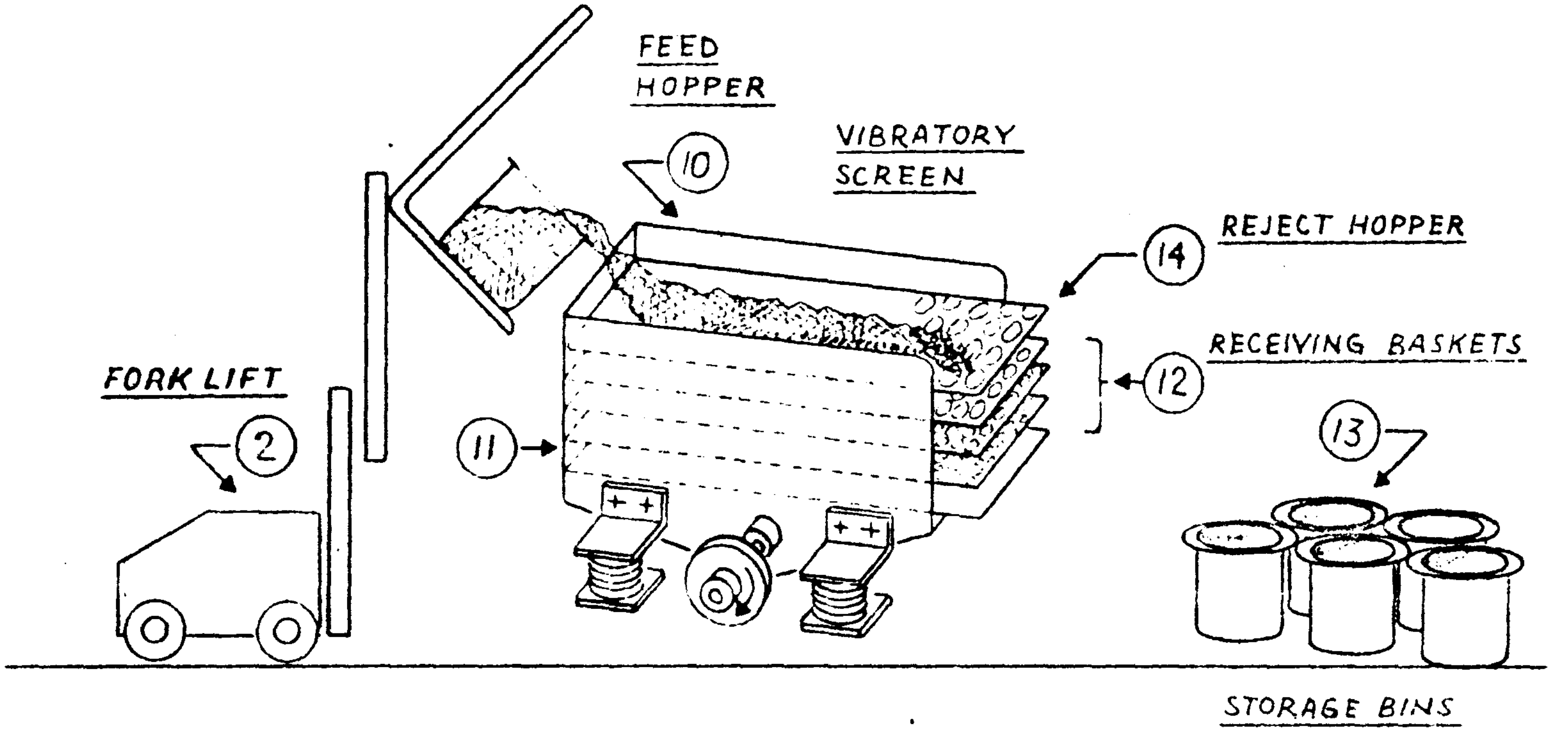


2. General-purpose forklift
6. Storage bins
7. Slat feed-conveyor with drive
8. Grinder and drive
9. Storage bins

PLATE 4	SOLID WASTE PILOT PLANT	GRINDING

STEP II: <u>GRINDING</u> - PLATE 4 ABOVE

The very largest particles received at the prototype plant (such as automobile tires and the like, which have been identified by inspection and separated by hand), as well as the middle- and large-sized-particle segments of the mixed solid wastes already separated by the trommel (see Step I), are transported from the storage bins (6) by the forklift (2) to the grinder-feed conveyor (7). This slat conveyor feeds the grinder (8), which pulps, shreds, tears, breaks, and reduces the materials to smaller size particles. The ground waste is added to the storage bins (9), already containing the smallest particles separated by the trommel, until a sufficient amount is accumulated for the sieving operation (see Step III, below).



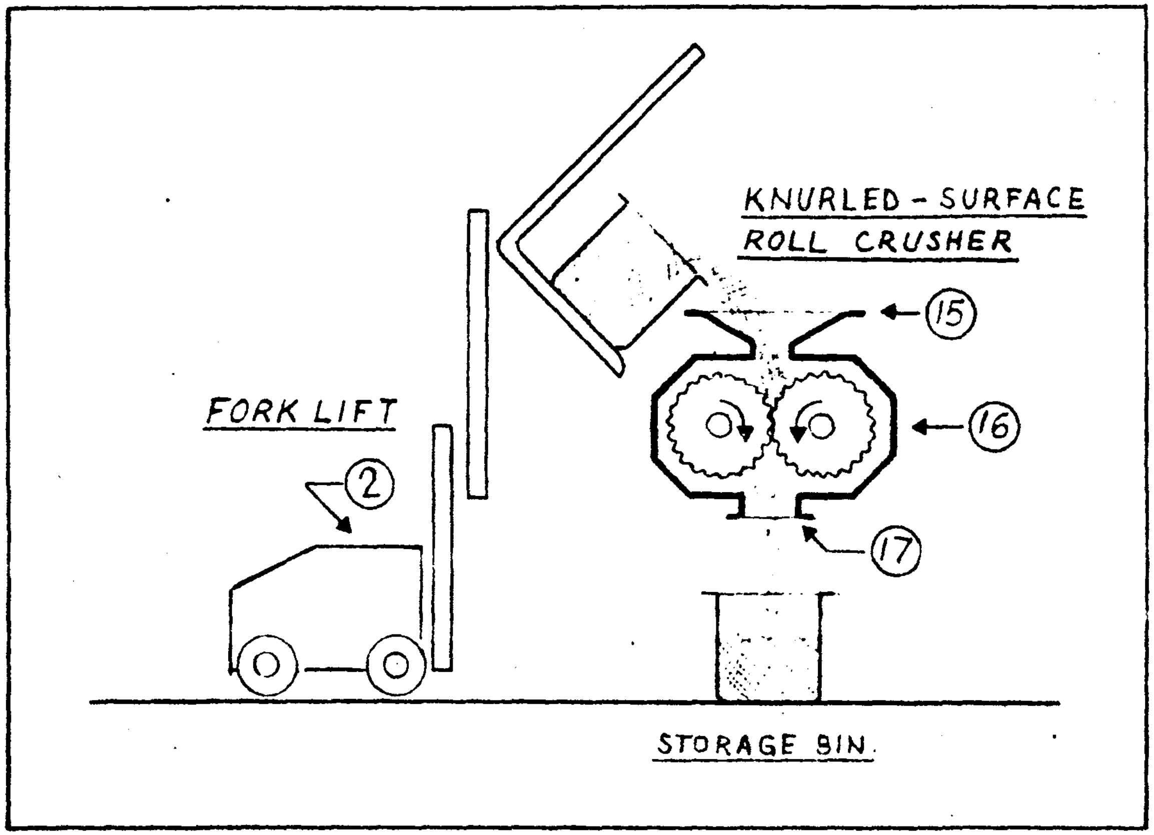
2. General-purpose forklift
10. Feed hopper
11. Vibratory screen and drive
12. Receiving baskets
13. Storage bins
14. Reject hopper

PLATE 5	SOLID WASTE PILOT PLANT	SIEVING

STEP III: SIEVING - PLATE 5 ABOVE

Output waste from Steps I and II must now be further classified according to size. The most efficient device for accomplishing this is a vibratory screen, which will not "blind," or close-up, with small, wetted particles of paper, garbage, etc. A series of vibratory screens either on line or one above the other has been suggested as a possible alternative to a single screen, for by then employing a graduated reduction in the size of the screen perforations a complete, single-run sizing could be made. Smaller particles may proceed from the screen in their respective size categories directly to the Bowerman Classifier (see Step V), while particles larger than a certain size will require additional shaping (see Step IV). Experience will in large measure determine the necessary capacity of this subsequent step.

In the diagram the forklift (2), delivers the ground waste to a feed hopper (10), from which it is fed to the vibratory screen (11) with its successively smaller perforations. Receiving baskets (12) at the end of each series of screen plates accommodate the separated materials by size. These are periodically dumped into separate storage bins (13) for retention until shaping or Bowerman Classifier operation. Particles too large either for shaping or for immediate Bowerman classification are caught in a reject hopper (14) and recycled through the grinder (Step II, above). Experience may show that only one or two screen-perforation sizes are necessary in this separation.



15. Feed hopper

16. Knurled-surface rolls

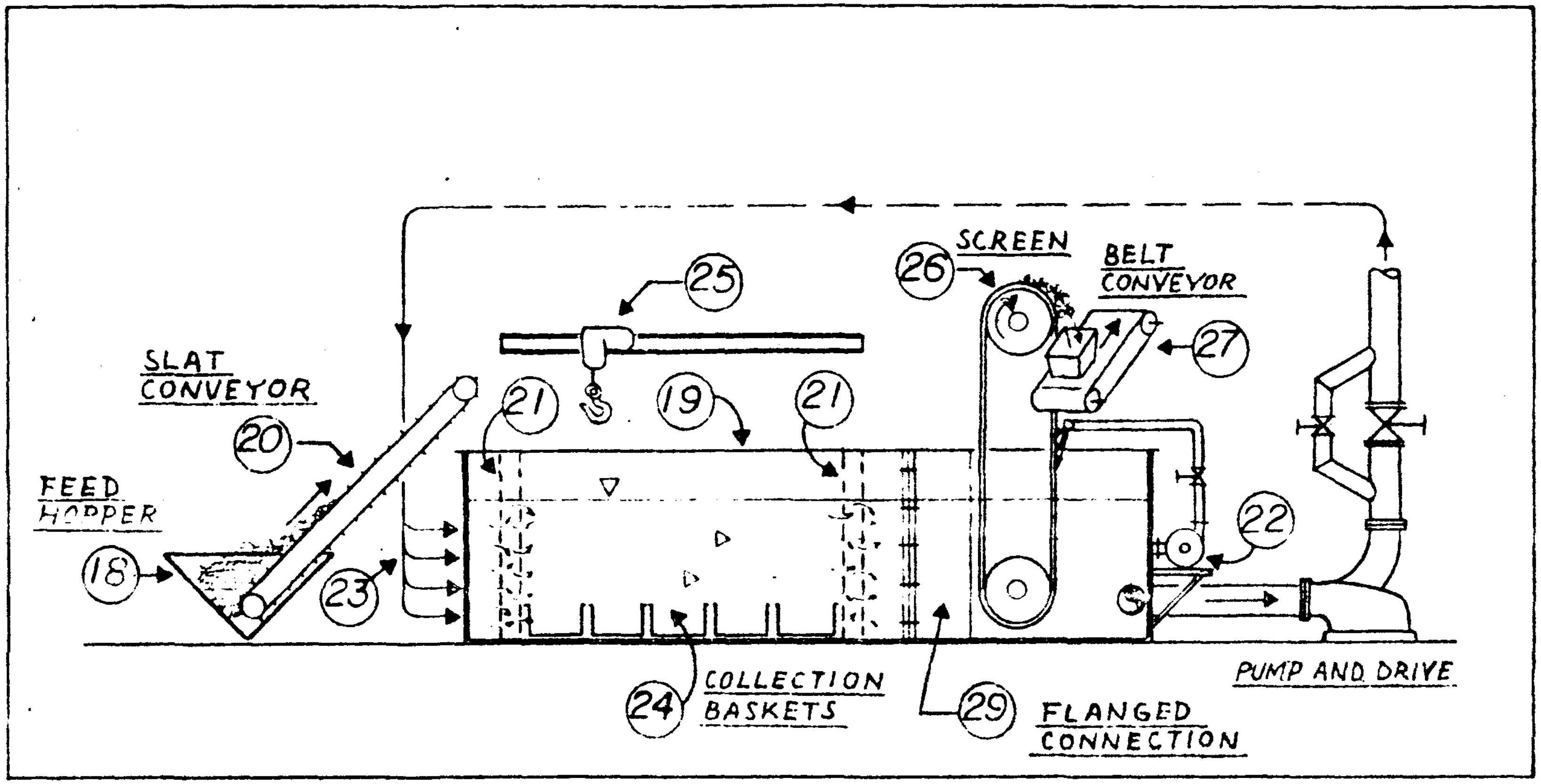
17. Discharge chute

PLATE 6 | SOLID WASTE PILOT PLANT | SHAPING

STEP IV: <u>SHAPING</u> - PLATE 6 ABOVE

Sized material is fed from the top of the shaping mill into a feed hopper (15) with a 4" x 4" safety grid and passes between two knurled-surface rolls (16) under high compression. The rolls may be operated at a speed differential to obtain grinding action. The gap between rolls is variable to permit experimentation at different loading rates and also to optimize size of the output material, depending on experience in subsequent classifying. A discharge chute (17) delivers the crushed, shaped material to a point above floor level, where it can be collected for resieving or for Bowerman classification.

It may prove in operation that smaller particles segregated in Step III above will need no further shaping and may proceed directly to the Bowerman Classifier; but it is virtually certain that larger particles will require the more refined shaping they will receive in this step than they will have already acquired in Steps I, II or III. Experience must be gained for an understanding of the influence of the rolls, particularly on metal particles. Since frangible materials such as glass will be further broken and powdered by the heavy-pressure mill, it may prove desirable to re-sieve the material to separate some of the very fine particles.



18. Feed hopper
19. Classifier tank (8' x 3' x 17')
20. Slat feed conveyor with variable-speed drive
21. Perforated baffles
22. Spray pump and drive
23. Distribution manifold
24. Removable collection baskets
25. Overhead monorail lift
26. Traveling screen with variable-speed drive
27. Flat belt conveyor and chute
28. Mesh-cleaning spray and nozzles
29. Flanged connection of Classifier tank (19) to traveling screen tank (31--Plate 8)

PLATE 7	SOLID WASTE PILOT PLANT	BOWERMAN CLASSIFIER

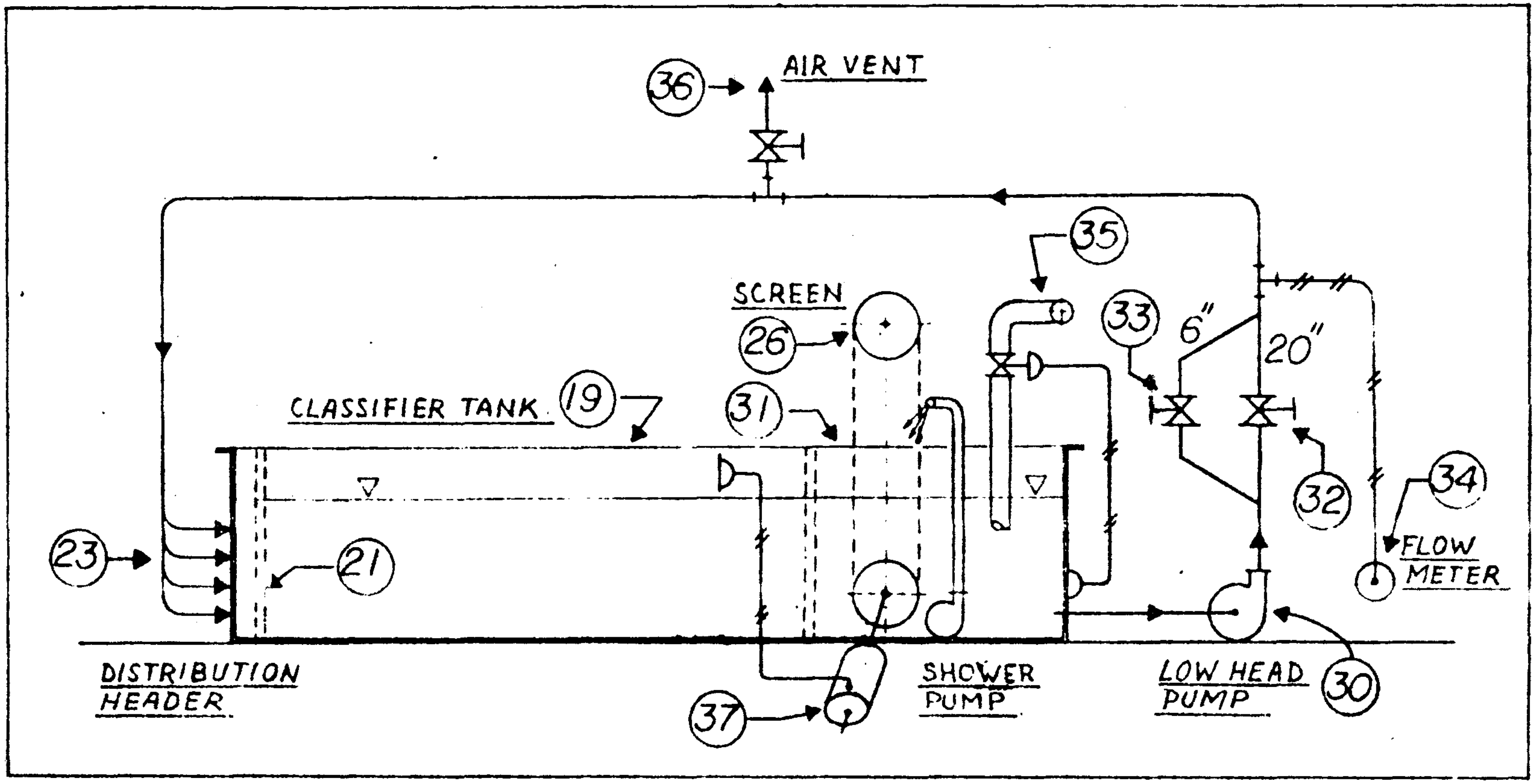
STEP V: BOWERMAN CLASSIFYING - PLATE 7 ABOVE

In the pilot plant project, operation of the Classifier is to be stepwise rather than continuous. Shaped solid wastes are dumped, one size-category at a time, into a watertight feed hopper (18), where they may be pre-wetted with the same fluid that is being used in the Classifier tank (19). An inclined slat conveyor (20) delivers the material to a carefully isolated discharge point just beyond the perforated upstream baffles (21). To ensure submergence, the particles may be further wetted here by fluid in a line from the spray pump (22). The perforated baffles, staggered with the distribution manifold (23), provide for uniform laminar flow of the tank fluid, necessary for proper Classifier operation.

As the particles fall through the fluid, the current carries them along until they collect in baskets (24) at the bottom of the tank. In general, heavy particles (ferrous metals, brass, copper, etc.) drop into the upstream baskets, while the lighter components (glass, aluminum, some plastics, etc.) are carried further downstream. It is unlikely, however, that the uniform separation of the baskets proposed for the initial runs of the pilot plant will produce segregated batches of material of nonoverlapping composition. Experience with the settling rates will correct this deficiency. An overhead monorail lift (25) removes the baskets so that the collected material can be evaluated.

The least dense components of the solid waste (especially floating particles of cellulose and plastics) are carried out of the tank with the fluid and removed by a traveling screen (26). This screen deposits them onto a flat belt conveyor, from which they are chuted (27) to a collection point at floor level. A final design which will accomplish this latter suboperation while simultaneously wringing fluid from the particles for return to the tank must await operational experience with the Classifier. The shower pump (22) and spray nozzles (28) continuously keep the mesh of the returning traveling screen open for drainage.

A separate schematic of a possible method of fluid flow control and instrumentation of the Bowerman Classifier follows on Plate 8.



19.	Classifier tank (8' x 3' x 17')	32.	18-inch geared gate valve
21.	Perforated baffles	33.	6-inch control valve
23.	Distribution Manifold	34.	Flow meter
30.	High-capacity, low-head pump and drive	35.	4-inch level control makeup line
31.	Traveling-screen tank	36.	Air vent
		37.	Automatically controlled, variable-speed traveling-screen drive

PLATE 8 | SOLID WASTE PILOT PLANT | HYDRAULIC SCHEMATIC

STEP V: <u>BOWERMAN CLASSIFICATION, CONTINUED: HYDRAULIC SCHEMATIC</u> - PLATE 8 ABOVE

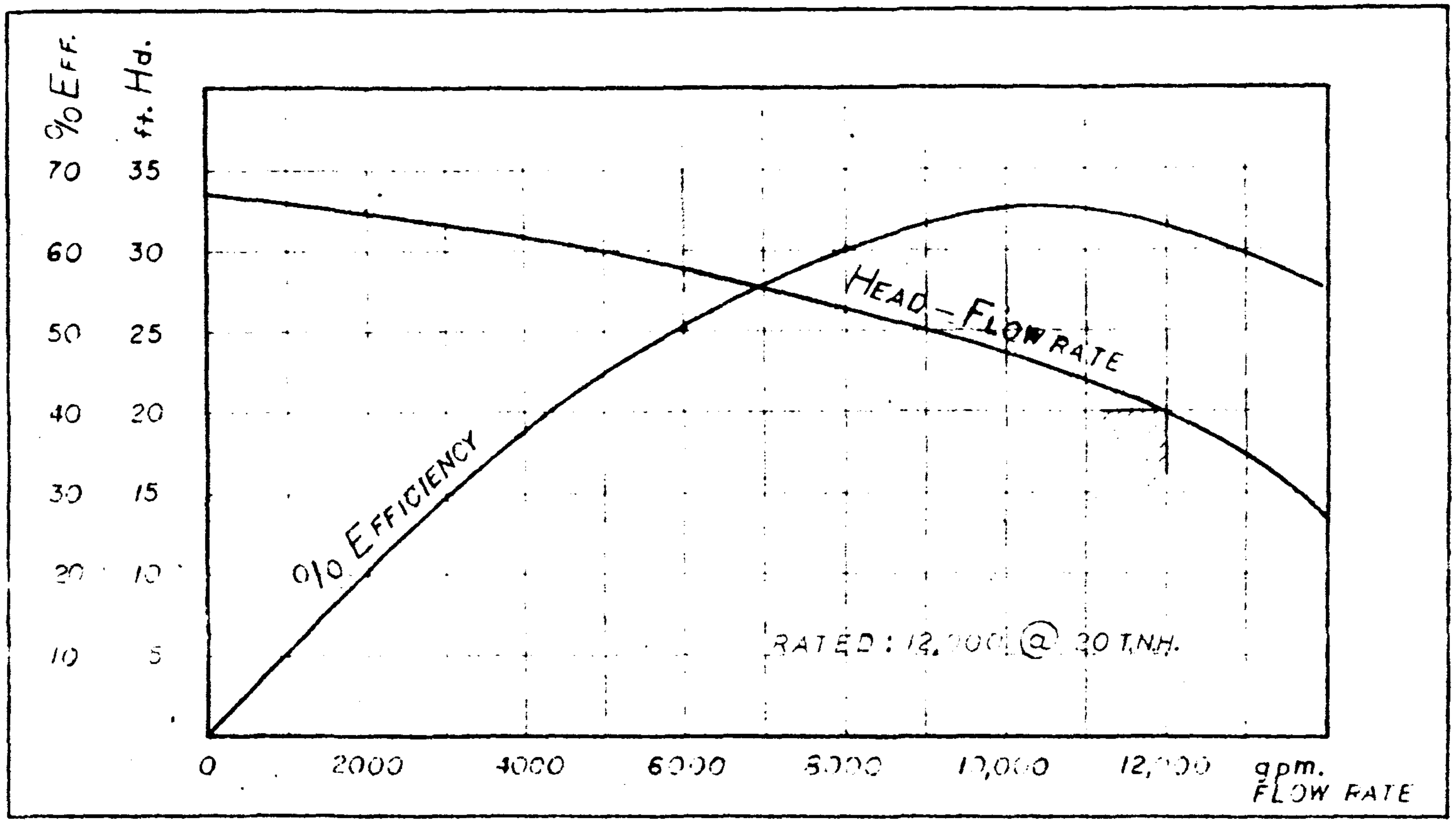
Plates 9a and 9b (following) demonstrate the nonlinear head-capacity and throttling characteristics for the low-head pump (30--Plate 8) and gate valve (32) arrangement, such as might be employed to control the circulation of the fluid through the Classifier tank (19), past the flanged connection (29--Plate 7), and through the traveling screen tank (31), for piping back to the distribution manifold (23). The pump design includes nonoverload characteristics, i.e., power cannot exceed the rated horsepower of the driving unit.

Any flow less than the maximum-rated 12,000 gpm at 20-foot head would require less power and might be attained by introducing in-cycle resistance in the form of a gate valve (32). Because the large gate valve can give neither proportionate nor precise control, a six-inch control valve (33) may be inserted in parallel with the main flow-cycle. This valve provides a vernier control of flow for the system which the large gate valve cannot accomplish by itself. Any required pumping rate from 12,000 to 1,200 gpm may thus not only be attained, but may also be reproduced by reference to a flow meter (34) in the line. Streamlined flow may be improved by placing a second partition of baffles (21) on the downstream end of the classifier tank, particularly when the classifier is used for the finer separation of settled materials collected in a prior run. These baffles must be removed when classifying prepared solid wastes with a high percentage of floating paper and plastics.

A four-inch makeup line (35) is automatically controlled for filling the system and maintaining level. An air vent (36) is placed at the high point of the piping to preclude air entrainment and subsequent air binding of the pumping system. The speed of the traveling-screen (37) is variable with head, i.e., as resistance builds up due to screen mesh becoming clogged, the increase in head on the upstream side (of screen) speeds up the screen travel and cleaning operation.

A typical start-up procedure follows:

1) Fill system with makeup valve opened.
2) Throttle gate valve to 1/4- to 1/2-open position.
3) Start pump at low rate of flow and evacuate all air from system.
4) Check flow rate on meter and gradually open large gate valve until approximate desired flow is attained.
5) Throttle six-inch vernier control to attain precise flow rate desired; the automatic makeup valve will now maintain the system in equilibrium.
6) Start spray pump to keep mesh of travelling screen open for free drainage.
7) Start conveyor feeding wastes to classifier tank.
8) Start reject belt conveyor on screen.



TYPICAL CENTRIFUGAL PUMP
HEAD-CAPACITY CURVE

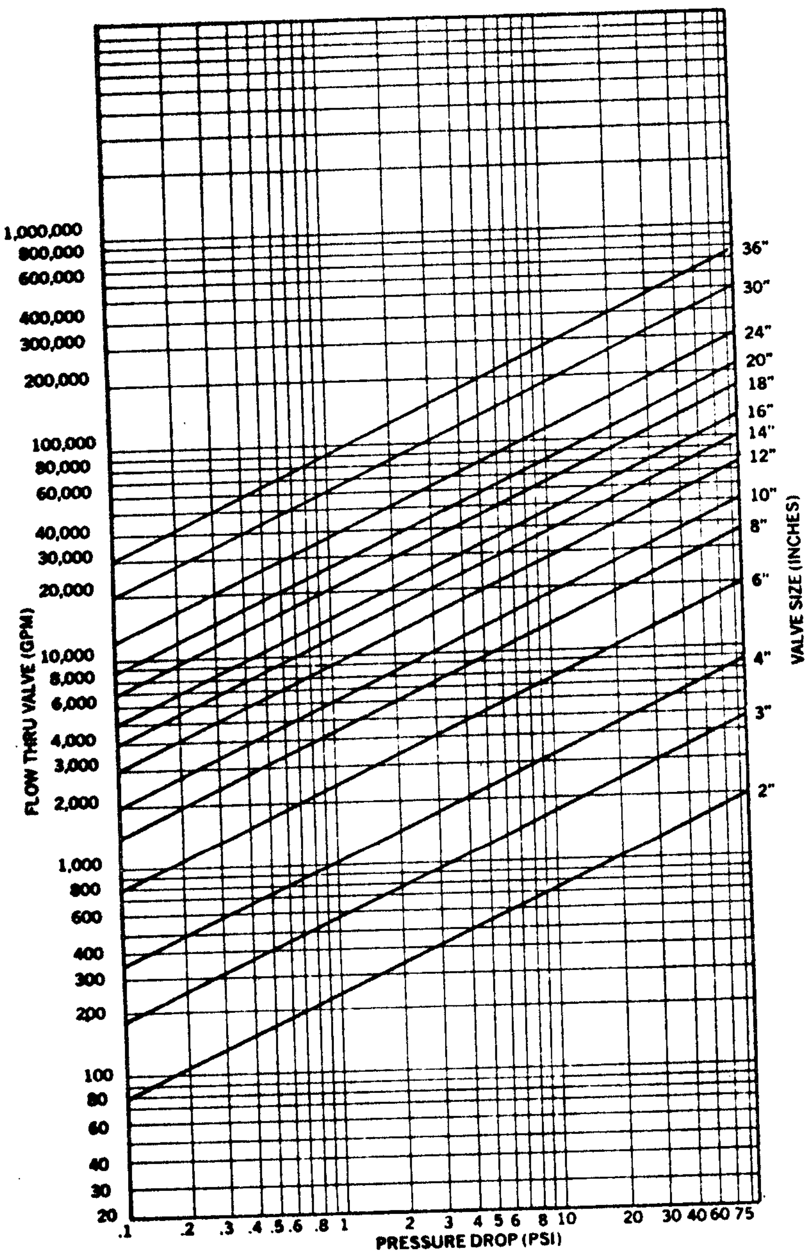
PLATE 9-A	SOLID WASTE PILOT PLANT	PUMP CAPACITY CURVES

valve sizing

PLATE 9-B*

metal seated valves (round port)

FLOW CHART—Valve Wide Open



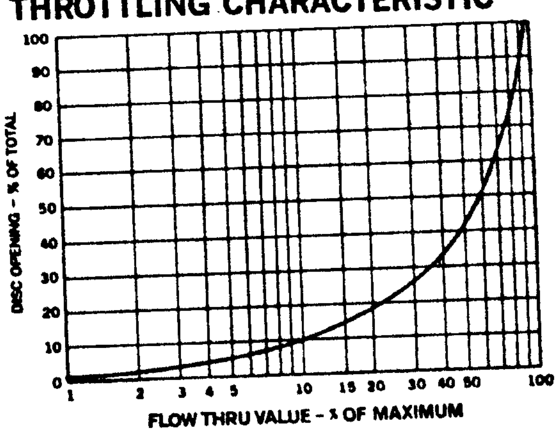
Cv VALUES
(Flow in GPM of water at 1 psi pressure drop)

VALVE SIZE	Cv	HEADLOSS* (Feet of Pipe)	AREA OF OPENING (Square Inches)
2"	240	2.5	3.14
3"	565	3.6	7.07
4"	1040	4.4	12.60
6"	2440	6.8	28.80
8"	4460	8.7	50.30
10"	6250	14.0	69.00
12"	9400	15.0	102.0
14"	12500	16.0	133.0
16"	16500	18.0	174.0
18"	21400	20.0	227.0
20"	27000	22.0	280.0
24"	39700	26.0	411.0
30"	62000	34.0	619.0
36"	93000	41.0	911.0

*Pressure drop in equivalent length (feet) of standard weight steel pipe.

Sizing based on discharge into conduit rather than atmosphere.

THROTTLING CHARACTERISTIC



*Source: DeZurik Corporation, Sartell, Minn. Bulletin 30.00-1, "Series L, Knife Gate Valves," February, 1971, page 4.

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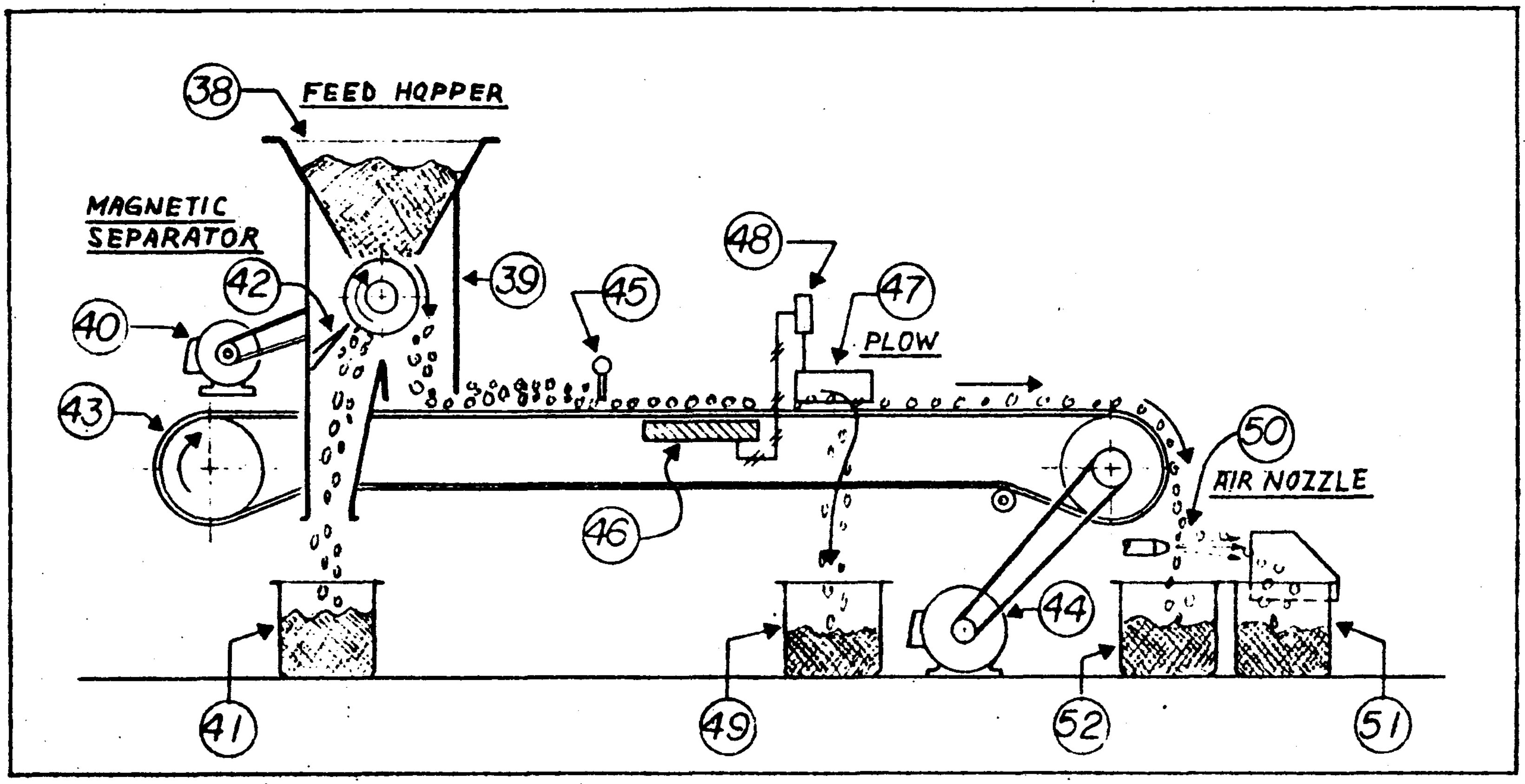

38. Feed hopper
39. 20-inch magnetic drum separator
40. Variable-speed drive
41. Ferrous-metals container
42. Scraper blade
43. 24-inch flat belt conveyor
44. Variable-speed drive
45. Leveling curtain
46. Metal-detection coil
47. Adjustable plow
48. Plow actuator (on signal from coil, 46
49. Nonferrous metals container
50. High-pressure air nozzle
51. "Light nonmetallics" container
52. "Heavy nonmetallics" container

PLATE 10	SOLID WASTE PILOT PLANT	HEAVY FRACTION SUB SYSTEM

STEP VI: HEAVY-FRACTION CLASSIFICATION - PLATE 10 ABOVE

The "heavy" (i.e., most dense) fraction of the material segregated in the Bowerman Classifier is now given additional refinement. A feed hopper (38) controls the delivery of the input material to a magnetic drum separator (39). A stationary permanent magnet holds ferrous particles onto a concentric rotating drum, powered by a variable-speed drive (40), until the particles move out of the magnetic field and are scraped off the drum into a container (41) by a scraper blade (42). Nonmagnetic particles drop over the drum without clinging to it and onto a belt conveyor (43), also provided with variable-speed drive (44). This material is flattened and spread as it moves along the belt by an adjustable leveling curtain (45), prior to passing a metal-detection coil (46).

The coil is "tuned" to detect fragments of nonferrous metal larger than a certain size, which are plowed (47) on signal (48) off the conveyor belt and into a container (49).

The smaller particles of nonferrous metals remain on the belt, along with other residues of plastics, glass, etc., and travel to the discharge point of the conveyor. As this material drops from the belt, it is met by a high-velocity jet of air (50), which is adjusted to blow less dense particles aside into a "light nonmetallics" container (51), while allowing the denser particles to fall through into a "heavy nonmetallics" container (52).

Postscript

The preceeding schematic account of the proposed prototype plant has been included for the clarity of this report. It is based on preliminary specifications developed by the Zurn Environmental Engineers and the ERIEZ Manufacturing Company prior to the actual drafting of the report. Yet while they are similar to these specifications, the schematics do not pretend to conform in every detail: several discrepancies have already been noted on pages 40-41. Such present recognition of alternative methods of dealing with various technical problems will undoubtedly serve to speed implementation, should the proposed project be given approval. It reflects some of the intensive critical evaluations in each area of the project, which have continued since the specifications were released. These original preliminary specifications are included for completeness below in Sections VI and VII.

SECTION VI: BOWERMAN CLASSIFIER

(AS ORIGINALLY DEVELOPED BY THE ZURN ENVIRONMENTAL ENGINEERS)

This section contains preliminary specifications developed by the Zurn Environmental Engineers of Zurn Industries, Inc., for the assembly of the grinding, sieving, shaping, and Bowerman Classifying units of the proposed pilot plant. As with the schematic diagrams of Section V, these specifications should in no way be considered final; indeed, variations between these designs and several ideas incorporated into the schematics have already been noted (see pages 40-41). In the drawings prepared by the Zurn Environmental Engineers the components mentioned above are arranged on two moveable skids, the "Stage One, Grinder" Skid (Plate 11) and the "Stage Two, Sorter" Skid (Plate 12). The reader is encouraged to refer to these plates as the narrative proceeds.

PART I: General

The Stage One, Grinder Skid consists of grinder, sieve, traveling screen, spray pump, tank, structural steel base, rolls, and miscellaneous electrical and mechanical support. The Stage Two, Sorter Skid consists of pump, drive, conveyor, baskets, accessories, piping, tank, skid, and electrical and mechanical support to the operation. As shown in the two plan views, the right end of the Bowerman Classifier in Stage II will be mated to the left end of the Stage I assembly by bolting the two gasketed connections together to make one integral hydraulic unit. A similar gasketed and bolted connection will be made between the twenty-inch pipe, connected to the valve on the Stage I platform, and the pump on the Stage II platform. The in-line connection of the two stages, rather than an L-shaped connection, was decided upon to maintain as uniform a flow as possible with velocity streamlines remaining nearly parallel up to the traveling water screen on the Stage I platform.

To place the assembled unit in service, the tank will be filled with an appropriate fluid to a depth of six feet, maintaining a free-board of two feet to the top of the tank. Inasmuch as the maximum impediment to fluid flow would occur at the upstream face of the water screen, the excessive clogging of that water screen with materials such as paper or plastic would simply cause the suction line to the pump to draw down the water level behind the screen, perhaps to a point of shutoff. Nevertheless, there is sufficient surge capacity in the two feet of free-board in the Classifier (Stage II) to prevent overflow of fluid even if the pump for the traveling water screen were slowed down to a point of shutoff. When filled with water, kerosene, or tricholorethylene, the system requires a 200 KVA external power supply to fulfill complete operating requirements specified herein.

The work under these specifications shall include the furnishing of all materials, labor, and equipment to construct and test the two skid-mounted units capable of being connected in the field, each consisting of mechanical, structural, and electrical equipment. This equipment is described in the following.

PART 2: Mechanical

2-01. Stage One, Grinder. Skid shall consist of one skid on which shall be mounted the grinder, the sieve, the traveling screen, spray pump, tank rolls, necessary access, power, lights, mechanical, and electrical support to the operation.

a. Grinder. An Eidal International Corporation solid waste reduction Model 75 Mini-Mill, or equivalent, shall be installed on the skid. Mini-Mill shall be complete in operating order with 75-horsepower, 460-volt, 3-phase, 60-Hertz motor for 460-RPM operation.

b. Sieve. The Contractor shall provide one Hewitt-Robins Model 16-30 contractor's sieve, or equivalent, complete with stainless steel perforated screens. The Hewitt-Robins sieve shall be modified to readily receive one of four 20-gauge stainless steel perforated screens constructed as follows:

1. Screen Number 1 shall be provided with 1-1/4-inch holes on 2-inch centers staggered throughout the active area of the screen.

2. Screen Number 2 shall be perforated with 5/8-inch holes on 1-inch centers staggered throughout the active area of the screen.

3. Screen Number 3 shall be constructed with 3/16-inch holes on 3/4-inch centers staggered throughout the active area of the screen.

4. Screen Number 4 shall be perforated with 3/32-inch holes on 1/2-inch centers staggered throughout the active area of the screen.

Sieve shall be mounted on the skid and connected for operation. Chutes shall be provided as shown on the plans.

c. Traveling Screen. The Contractor shall provde a 6-feet-wide by 12-feet-high shaft traveling water screen such as that manufactured by Rex Chainbelt, Inc., complete with all operating accessories, and a 1-1/2 horsepower variable-speed drive for 0.2 to 2 feet-per-minute screen travel. The 32-mesh screen and chain assembly shall be corrosion resistant; a spare set of 8-mesh screen trays shall be provided for replacement. Buna N or wood seals shall be installed to provide 1/32 inch clearance in the fluid stream.

Spray header shall have a throttling valve. The trash collecting trough shall be integral with main assembly. Pressure grease lubrication shall be provided to all points from the variable drive adjustment position at tank top. Fluid drive and shear pins shall be used to protect the equipment. Screen shall operate from 6 feet normal depth to 7-1/2 feet flow depth but shall be capable of operating with a 5 feet intake water head.

d. Spray Pump. The Contractor shall provide one all iron worthington 1-1/2-CNF-74 open impeller, end suction Monobloc centrifugal traveling screen spray pump, or equivalent, for 150 gpm, 220 feet total dynamic head operation. Pump shall be equipped with 20 horsepower motor and protected by a suction strainer.

e. Tank. The 6 feet by 11 feet tank and traveling water screen enclosure on the Stage One, Grinder skid shall be constructed per these specifications.

f. Rolls. The Contractor shall provide an adjustable variable speed rolling mill consisting of two 6-inch diameter by 2 feet long Hastelloy knurled surface rolls, or equivalent, with a nontouching adjustable gap of 3/16 inch to 3 inches positioned by a 2,000 pound spring compression and protected by a shear pin arrangement. Feed shall be downward and discharge shall be outward. Feed hopper shall have 4 inch by 4 inch safety grid and discharge at least 2 feet above base. Variable 20:1, 10 horsepower electric drives shall be provided to obtain 0.75 to 15 feet per second peripheral speed on one roll and 0.5 to 10 feet per second peripheral speed on the other roll.

g. Miscellaneous. Butterfly valve shall be 20 inch water type tight shutoff. The necessary metering, pressure guages, and temperature guages shall be provided.

2-02. Stage Two, Sorter shall consist of one skid on which shall be mounted the pump, drive, conveyor, accessories, piping, tank, motor control center, and electrical and mechanical support to the operation.

a. Pump. The Contractor shall provide one 20-inch horizontal, single-stage, axial flow Cascade propeller pump of all iron, bronze fitted construction with stainless type 416 pump shaft. Pump performance shall be 12,000 gpm water at 20 feet total dynamic head and 80 percent efficiency; pump shall be capable of 1,200 gpm at a lesser head and efficiency (see Plates 9-A and 9-B). Packing shall be compatible with the various fluids specified.

b. Pump Drive. The Contractor shall provide one 100-horsepower 440-volt, 3-phase, 60-Hertz motor drive connected to a 10:1 manually adjustable variable speed drive with all accessories complete and operating on a continuous baseplate with the pump above to provide 1,200 to 12,000 gpm pump capacity.

c. Conveyor. A portable inclined conveyor approximately 20 feet long and 30 inches wide shall be provided with the variable speed motor, alowing belt speeds of 50 to 20 feet per minute. Belt shall be of natural rubber with 1-1/2 inch flights on 12 inch centers. Feed shall be through a 25 cubic feet open water tight hopper at grade. Motor connection shall be through a Crouse Hinds waterproof connector to skid. Conveyor shall have sufficient rigidity to be relocated by crane.

d. Accessories.

1. A 1/2 ton Yale and Towne chain hoist, or equivalent, with 20 feet of chain and hook shall be mounted on monorail above tank.

2. The necessary metering, pressure guages, and temperature guages shall be provided.

3. The Contractor shall provide four (4) 2 feet 9 inch by 6 foot high baffle plates of 1/4 inch 316 stainless steel with 3 inch diameter holes in staggered rows to provide at least 50 percent open area. Offset row pattern is to be reversed on two of the baffle plates.

e. Piping. Piping shall be ASTM A-120 black welded pipe, Schedule 40 for 5 inch diameter and smaller Schedule 20 for 6 inch diameter and larger. All welded construction with ASA 125 pound flange connections is permitted for 3 inch diameter and larger at pump, valves, etc. If a piping assembly exceeds 20 feet in length, a flanged union shall be provided. Screwed fittings with appropriate unions shall be used for smaller sizes.

Part 3: Structural Steel

a. The work covered by this section includes the furnishing and installation of the tank, skids, machinery support, access platforms and ladders, inspection windows, and miscellaneous metal.

b. Tank. The structural steel water tank shall consist of two sections each constructed of 1/4 inch steel plate reinforced with 4-inch by 4-inch I-beam columns which are extended to become the overhead chain hoist support. The Stage Two, Sorter skid tank is 3 feet wide by 8 feet high by 17 feet long. The Stage One, Grinder skid tank is 3 to 6 feet wide by 8 feet high by 11 feet long. The 4-inch by 4-inch I-beam columns become tank reinforcing and traveling screen support.

c. Skid. The Contractor shall provide two rigid structural steel bases for support of the tank and equipment. Appropriate dimensions are 6 feet by 28 feet long and 6 feet by 17 feet long. Necessary eye bolts for hoisting and slots for forklift truck lifting shall be provided. Nonskid floor plates shall cover entire machinery area.

d. Machinery Bases. The Contractor shall provide machinery bases as required for rigid mounting of machinery. Stowage shall be provided for rail or truck transportation.

e. Inspection Windows. Four inspection windows approximately 12 inches by 12 inches shall be provided on the side of the tank opposite the lights.

f. Walkway. A 24-inch walkway shall be provided along the full length of the tank and both sides of traveling screen. Handrails shall be provided as required for safety.

g. Baskets. The Contractor shall provide five baskets approximately 33 inches by 33 inches by 5 inches deep. Baskets are to be constructed of 3/8 inch rod and rigid to a loading to 20 pounds per square foot of a 32 mesh on bottom of the basket. Sides shall be solid; baskets shall be provided with stabilized handle lift.

Part 4: Electrical

4:01 General Requirements. The work covered by this section consists of furnishing all labor, materials, and equipment required to install a complete operable electrical system on each of the skids from a 440-volt, 3-phase, 60-Hertz, external source. System shall include 3-phase service pole, transformer, electric motors, starters, lighting panel, and power panel on the Stage Two, Sorter skid,with lighting and power system for complete operation.

a. Panel. The NEMA IV, or equivalent, control panel shall contain motor starters, transformer, lighting panel, metering station, main disconnect with voltmeter and ammeter, instruments and controls. All integral motor starters shall have a load ammeter. All motor starters shall have "off" and "run" lights. Circuit breakers shall be of the molded case type.

b. Motors. Electric motors shall be the squirrel cage induction type of weatherproof construction with weatherproof start-stop push button stations at each motor location. Motors 1/3-horsepower and above shall be designed for 440-volt, 3-phase, 60-Hertz operation. Smaller motors shall be the 120-volt, single-phase, type.

c. Lighting. Twenty-five foot candles of overhead lighting shall be provided at each work station. All lighting fixtures shall be sealed, dust-tight construction.

d. Outlets. One 440-volt, 3-phase, 60-Hertz, 60-ampere welding receptacle with cover shall be provided at the motor control center and one duplex 110-volt, single-receptacle with cover shall be provided for each skid.

e. Connectors. Power connections between skids and between skid and portable equipment shall be of weatherproof lock tight connectors with three feet of cable to each half.

f. Conduit. All conduit shall be PVC coated metal.

Part 5: Painting

All wetted and splash areas shall be unpainted carbon steel except where otherwise specified. Remaining exterior surfaces shall be sandblasted to near-white condition, primed with Koppers Zinodic-O and finished with Koppers Dynacol 35 HB.

Part 6: Test and Operations

System shall be field assembled at the manufacturer's shop, filled with water and all operable machinery tested with one ton of sample material.

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4:01 General Requirements. The work covered by this section consists of furnishing all labor, materials, and equipment required to install a complete operable electrical system on each of the skids from a 440-volt, 3-phase, 60-Hertz, external source. System shall include 3-phase service pole, transformer, electric motors, starters, lighting panel, and power panel on the Stage Two, Sorter skid,with lighting and power system for complete operation.

a. Panel. The NEMA IV, or equivalent, control panel shall contain motor starters, transformer, lighting panel, metering station, main disconnect with voltmeter and ammeter, instruments and controls. All integral motor starters shall have a load ammeter. All motor starters shall have "off" and "run" lights. Circuit breakers shall be of the molded case type.

b. Motors. Electric motors shall be the squirrel cage induction type of weatherproof construction with weatherproof start-stop push button stations at each motor location. Motors 1/3-horsepower and above shall be designed for 440-volt, 3-phase, 60-Hertz operation. Smaller motors shall be the 120-volt, single-phase, type.

c. Lighting. Twenty-five foot candles of overhead lighting shall be provided at each work station. All lighting fixtures shall be sealed, dust-tight construction.

d. Outlets. One 440-volt, 3-phase, 60-Hertz, 60-ampere welding receptacle with cover shall be provided at the motor control center and one duplex 110-volt, single-receptacle with cover shall be provided for each skid.

e. Connectors. Power connections between skids and between skid and portable equipment shall be of weatherproof lock tight connectors with three feet of cable to each half.

f. Conduit. All conduit shall be PVC coated metal.

Part 5: Painting

All wetted and splash areas shall be unpainted carbon steel except where otherwise specified. Remaining exterior surfaces shall be sandblasted to near-white condition, primed with Koppers Zinodic-O and finished with Koppers Dynacol 35 HB.

Part 6: Test and Operations

System shall be field assembled at the manufacturer's shop, filled with water and all operable machinery tested with one ton of sample material.

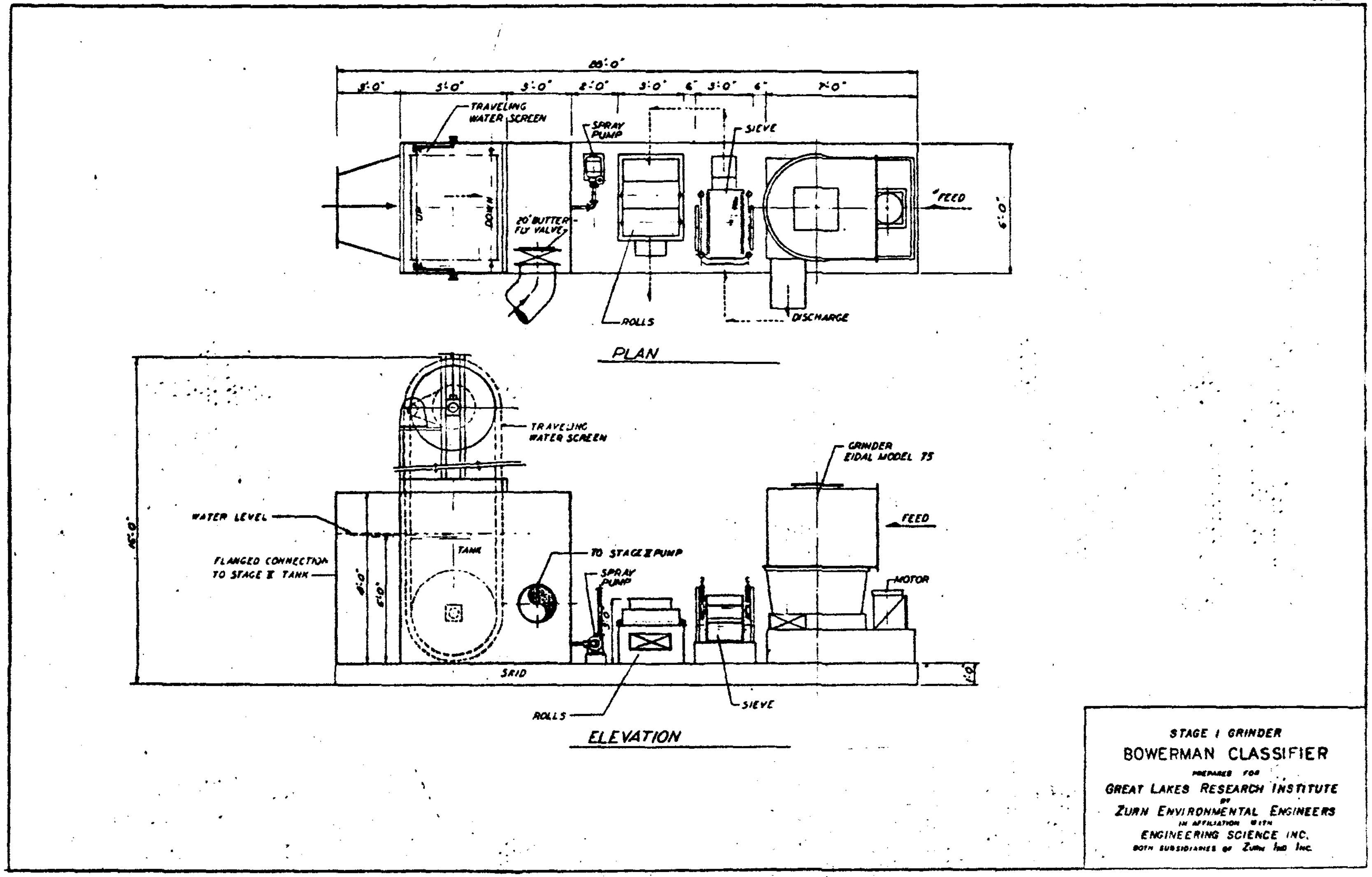


FIGURE
PLAN
ELEVATION
TRAVELING WATER SCREEN
SPRAY PUMP
SIEVE
FEED
20" BUTTERFLY VALVE
ROLLS
DISCHARGE
WATER LEVEL
FLANGED CONNECTION TO STAGE II TANK
TANK
TO STAGE II PUMP
GRINDER EIDAL MODEL 75
MOTOR
SKID
STAGE I GRINDER
BOWERMAN CLASSIFIER
GREAT LAKES RESEARCH INSTITUTE
ZURN ENVIRONMENTAL ENGINEERS
ENGINEERING SCIENCE INC.

Plate 11

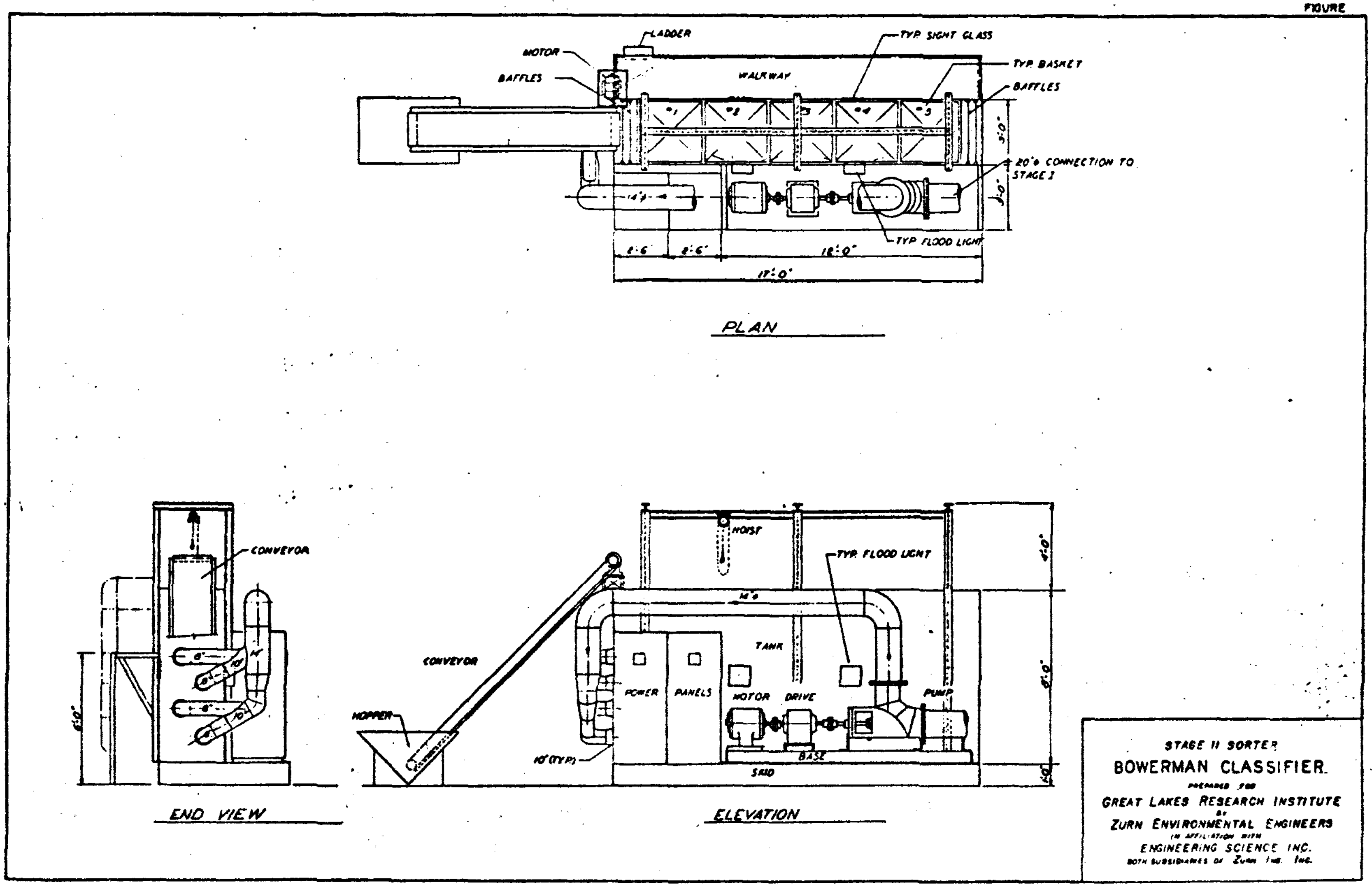


FIGURE
LADDER
MOTOR
BAFFLES
WALKWAY
TYP. SIGHT GLASS
TYP. BASKET
BAFFLES
3'-0"
20"φ CONNECTION TO STAGE I
4'-0"
TYP. FLOOD LIGHT
2'-6"
2'-6"
12'-0"
17'-0"
PLAN
CONVEYOR
END VIEW
HOPPER
CONVEYOR
HOIST
TYP. FLOOD LIGHT
14"φ
TANK
POWER
PANELS
MOTOR
DRIVE
PUMP
BASE
SKID
10"(TYP.)
6'-0"
8'-0"
ELEVATION
STAGE II SORTER
BOWERMAN CLASSIFIER
GREAT LAKES RESEARCH INSTITUTE
ZURN ENVIRONMENTAL ENGINEERS
ENGINEERING SCIENCE INC.

Plate 12

Section VII: Heavy-Fraction Subsystem

(As Originally Developed by the Eriez Manufacturing Company)

This section provides the detailed specifications and drawings of the heavy-fraction subsystem produced by the ERIEZ Manufacturing Company. The overall system is represented pictorially by Plate 13 (page 79) and dimensionally by Plate 14 (page 80).

The system is designed to give most efficient separation on dry, shredded particles up to three inches in diameter into magnetics, non-magnetic metallics, and two different-density groups of nonmetallics. Material up to five inches in diameter will, however, be permitted to pass.

In order to achieve this separation the input material must be fed uniformly, without surges, into the entry point of the system. The system is designed to process the particles at a rate of one-half ton per hour. Although all separate functions are tied together into one continuous feed belt, each is variable in speed, wipers and deflectors are variable in rigidity, and the quantity of material run can be varied. Thus a true pilot study of the system can be made.

General Specifications

CONTAINERS - must be light weight and portable. Material is reinforced plastic. Quantities of each size required are given below:

QUANTITY	SIZE
2	24" sq. x 24" high
1	16" sq. x 24" high
2	16" sq. x 20" high

UTILITIES - approximately 4 cubic feet per minute of 75 to 150 psi air is required. Electric power should be 220/440 volts, AC, 60 cycle.

Specifications and descriptions as well as operating variables for the separate functions of the system follow.

An alternate device for the separation of nonmagnetic metallics from nonmetallics has been proposed, and the drawings and specifications are included as Appendix C.

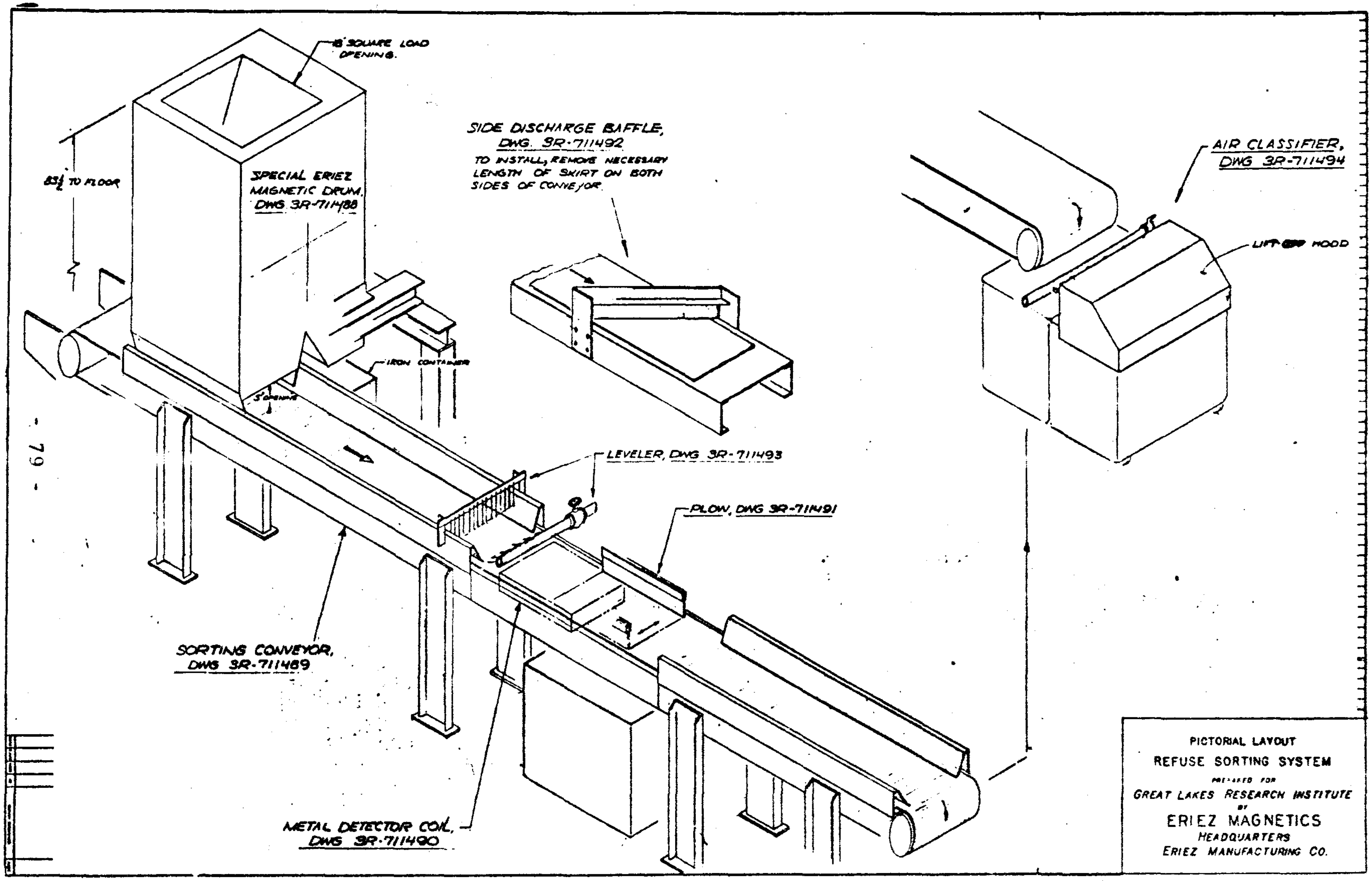
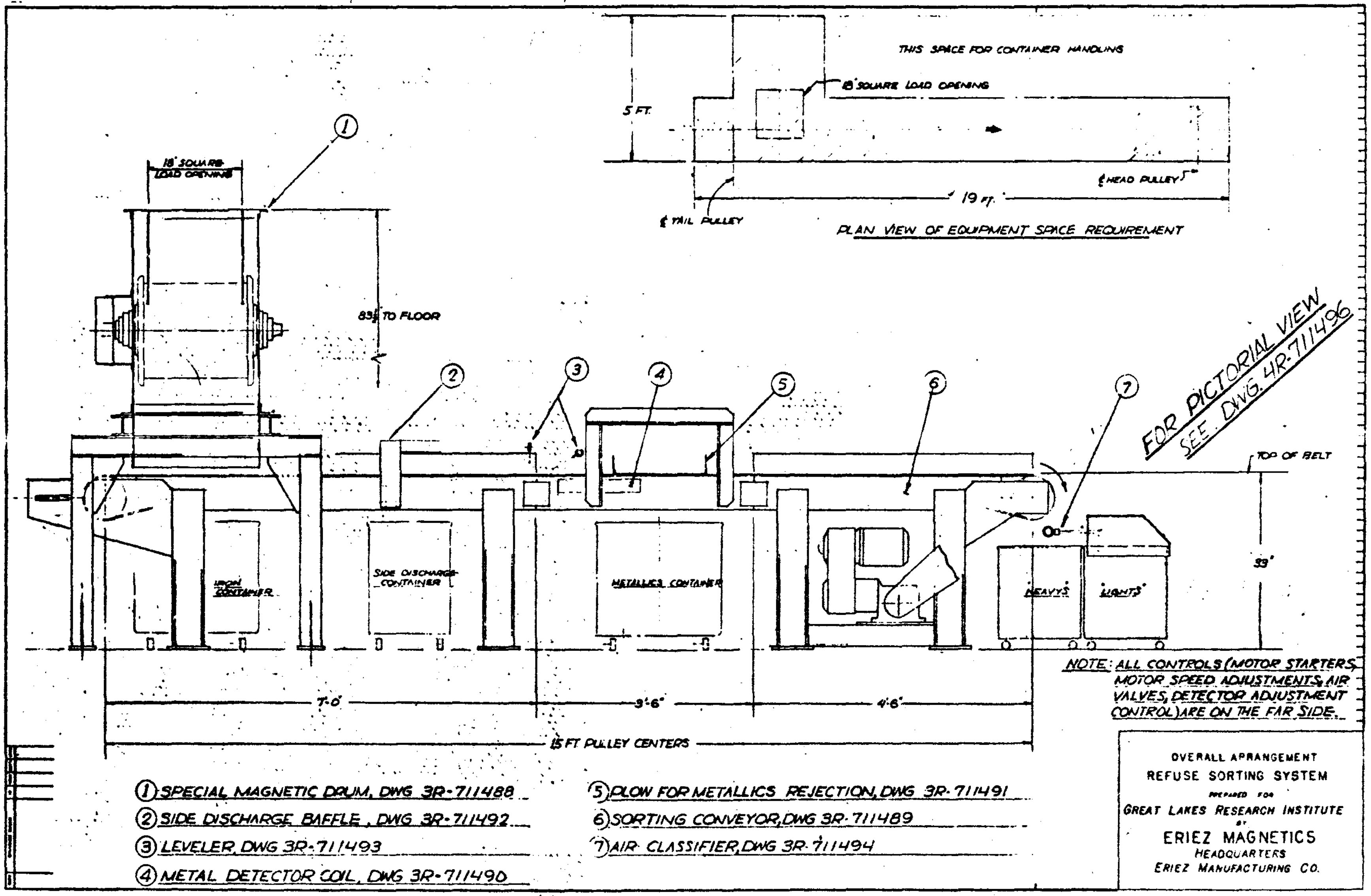
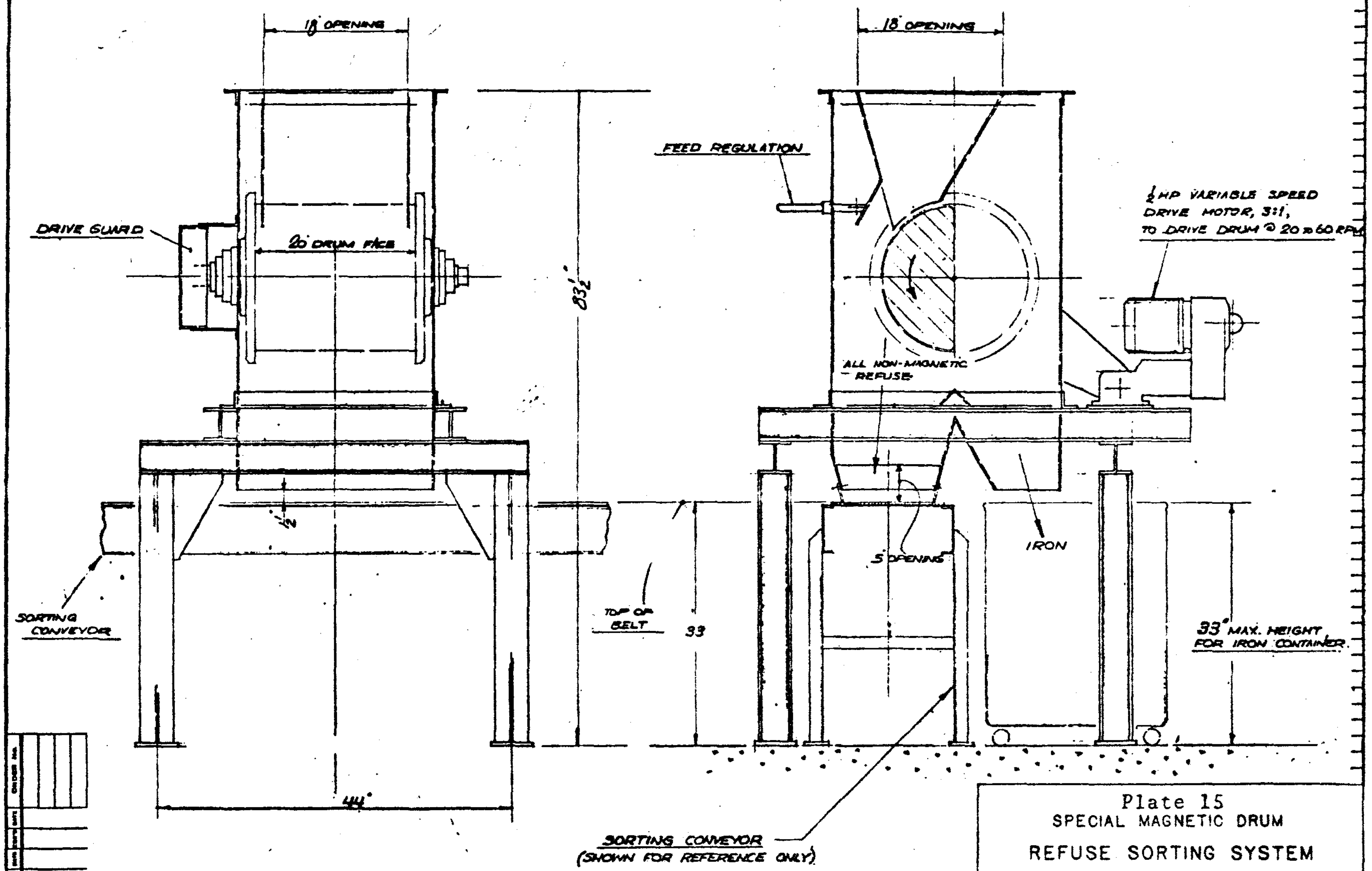

18" SQUARE LOAD OPENING.
83½ TO FLOOR
SPECIAL ERIEZ MAGNETIC DRUM, DWG 3R-711488
IRON CONTAINER
SIDE DISCHARGE BAFFLE, DWG. 3R-711492
TO INSTALL, REMOVE NECESSARY LENGTH OF SKIRT ON BOTH SIDES OF CONVEYOR.
AIR CLASSIFIER, DWG 3R-711494
HOOD
LEVELER, DWG 3R-711493
PLOW, DWG 3R-711491
SORTING CONVEYOR, DWG 3R-711489
METAL DETECTOR COIL, DWG 3R-711490
PICTORIAL LAYOUT
REFUSE SORTING SYSTEM
GREAT LAKES RESEARCH INSTITUTE
ERIEZ MAGNETICS
HEADQUARTERS
ERIEZ MANUFACTURING CO.

Plate 13



THIS SPACE FOR CONTAINER HANDLING
18" SQUARE LOAD OPENING
5 FT.
℄ HEAD PULLEY
19 FT.
℄ TAIL PULLEY
PLAN VIEW OF EQUIPMENT SPACE REQUIREMENT
18" SQUARE LOAD OPENING
83½" TO FLOOR
FOR PICTORIAL VIEW SEE DWG. 4R-711496
TOP OF BELT
33"
IRON CONTAINER
SIDE DISCHARGE CONTAINER
METALLICS CONTAINER
HEAVYS
LIGHTS
7'-0"
3'-6"
4'-6"
15 FT PULLEY CENTERS
NOTE: ALL CONTROLS (MOTOR STARTERS, MOTOR SPEED ADJUSTMENTS, AIR VALVES, DETECTOR ADJUSTMENT CONTROL) ARE ON THE FAR SIDE.
(1) SPECIAL MAGNETIC DRUM, DWG 3R-711488
(2) SIDE DISCHARGE BAFFLE, DWG 3R-711492
(3) LEVELER DWG 3R-711493
(4) METAL DETECTOR COIL, DWG 3R-711490
(5) PLOW FOR METALLICS REJECTION, DWG 3R-711491
(6) SORTING CONVEYOR, DWG 3R-711489
(7) AIR CLASSIFIER, DWG 3R-711494
OVERALL ARRANGEMENT
REFUSE SORTING SYSTEM
PREPARED FOR
GREAT LAKES RESEARCH INSTITUTE
BY
ERIEZ MAGNETICS
HEADQUARTERS
ERIEZ MANUFACTURING CO.

Plate 14



ERIEZ 18" DIA. - 20" FACE PERMANENT
MAGNETIC DRUM IN SPECIAL HOUSING
WITH SUPPORT BASE TO STRADDLE
SORTING CONVEYOR...

Plate 15
SPECIAL MAGNETIC DRUM

REFUSE SORTING SYSTEM

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BY
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HEADQUARTERS
ERIEZ MANUFACTURING CO.

Special Magnetic Drum - PLATE 15 ABOVE

The unit is self standing and driven independently of any other area of the system. Therefore, it can be moved away from the system so that other methods of feed to the belt conveyor can be studied and so that other methods of magnetic separation can be evaluated. (A suspended self-cleaning magnet over the conveyor is a method of magnetic separation worth consideration, although its merit will depend on space limitations, etc.)

The magnetic drum in housing has been selected as most applicable to this system considering all variables. Permanent magnetic material is Erium 25, stable between zero and 150 degrees F. Drive speed is variable and allows drum rotation speeds between 20 and 60 rpm. (Normal fixed speed of magnetic drums of this size is 35 rpm.)

Nonmagnetics will be discharged directly onto the sorting conveyor belt and magnetics into a portable container set under the iron discharge opening.

A feed regulation deflector is provided to prevent material fed onto the drum from bouncing out of the magnetic influence field of the drum. The regulation deflector is <u>not</u> to meter material out of the feed hopper, as the material to be run will not feed in this manner. It must be kept moving or it will pack.

Adequate access panels are built into the drum housing to allow internal adjustments on deflectors and to visibly examine flow through the drum housing. Construction material for the drum and housing is further described in ERIEZ Bulletin SB-340.

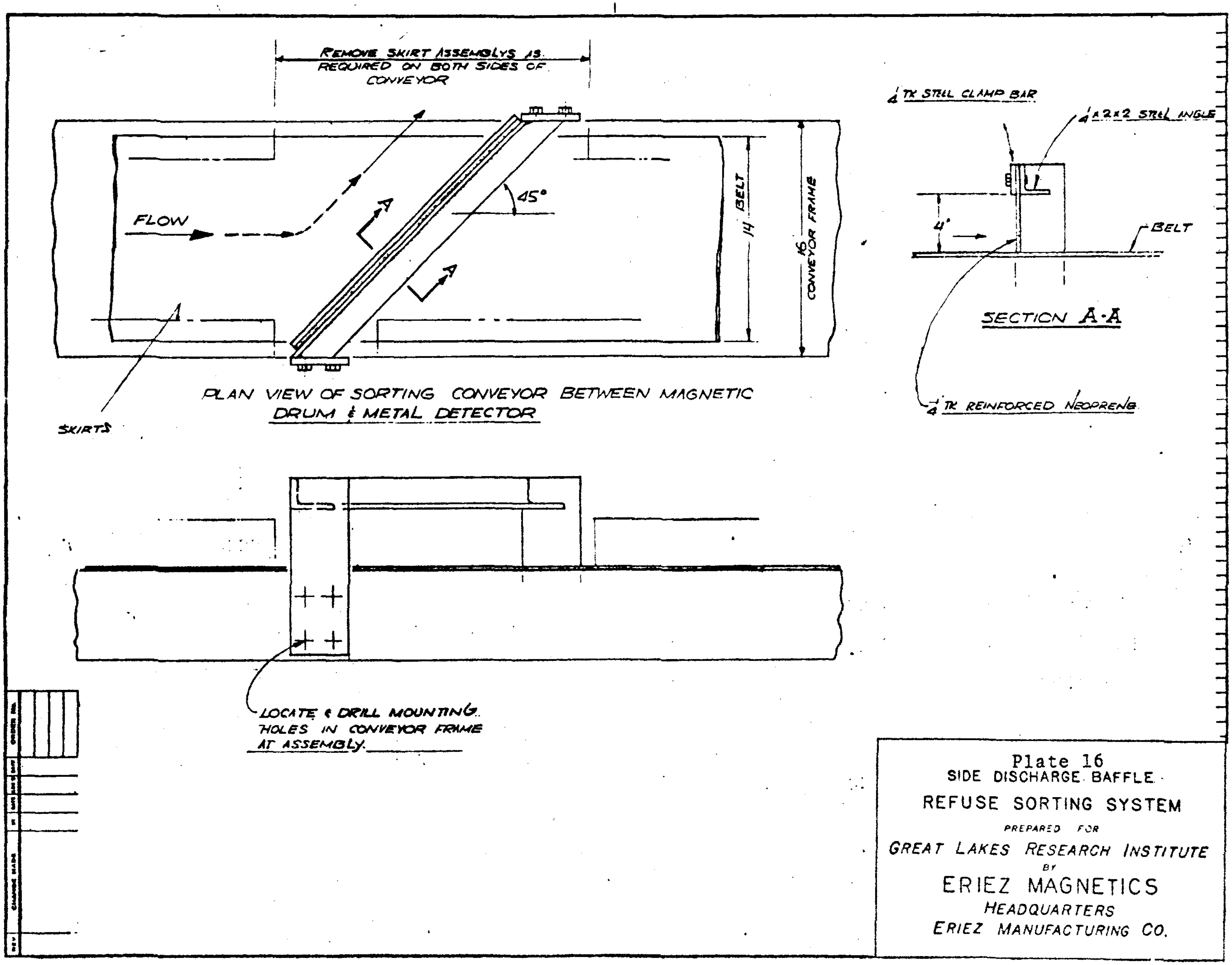

Plate 16
SIDE DISCHARGE BAFFLE
REFUSE SORTING SYSTEM
PREPARED FOR
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ERIEZ MANUFACTURING CO.

Side Discharge Baffle - PLATE 16 ABOVE

When multiple stage magnetic separation is to be studied and evaluated, the side discharge baffle will be mounted as shown in the area between the discharge of the magnetic drum and the metal detector coil. In this area of the conveyor it will be necessary to remove short lengths of skirts on both sides of the conveyor. Material deflected by the baffle will discharge into a portable container.

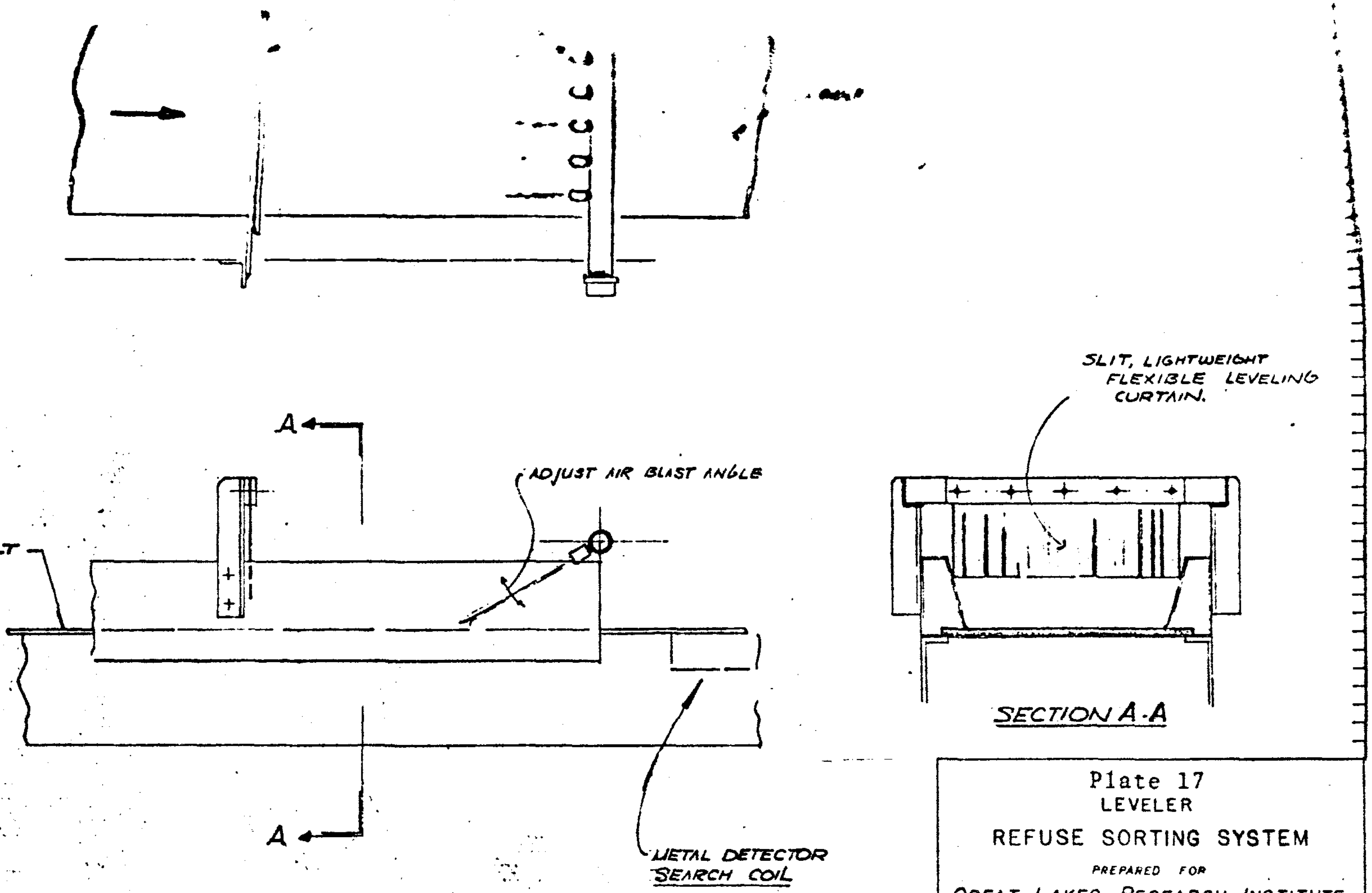

Plate 17
LEVELER

REFUSE SORTING SYSTEM

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BY

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ERIEZ MANUFACTURING CO.

LEVELER - PLATE 17 ABOVE

While the magnetic drum will spread out the material on the sorting belt, some items may bounce and lie on others, particularly when either the drum or conveyor belt is operating at or near its highest speeds. For best operations from the metal detector and rejection station the material reaching this area should be as level and spread out as possible. Experimentation and adjustment with the leveling curtain and air blast will perfect this function. Items are described on the plates. The curtain material and its degree of stiffness can be finalized only after actually running the system. It is advisable to furnish several curtains of different length and stiffness with the initial unit.

Structural items and piping are steel and should be mounted so that they can be easily moved (or removed, if the nature of the operation does not warrant them).

Air for the leveler system is 75 to 150 psi and is from the source also supplying the plow cylinder further down the belt.

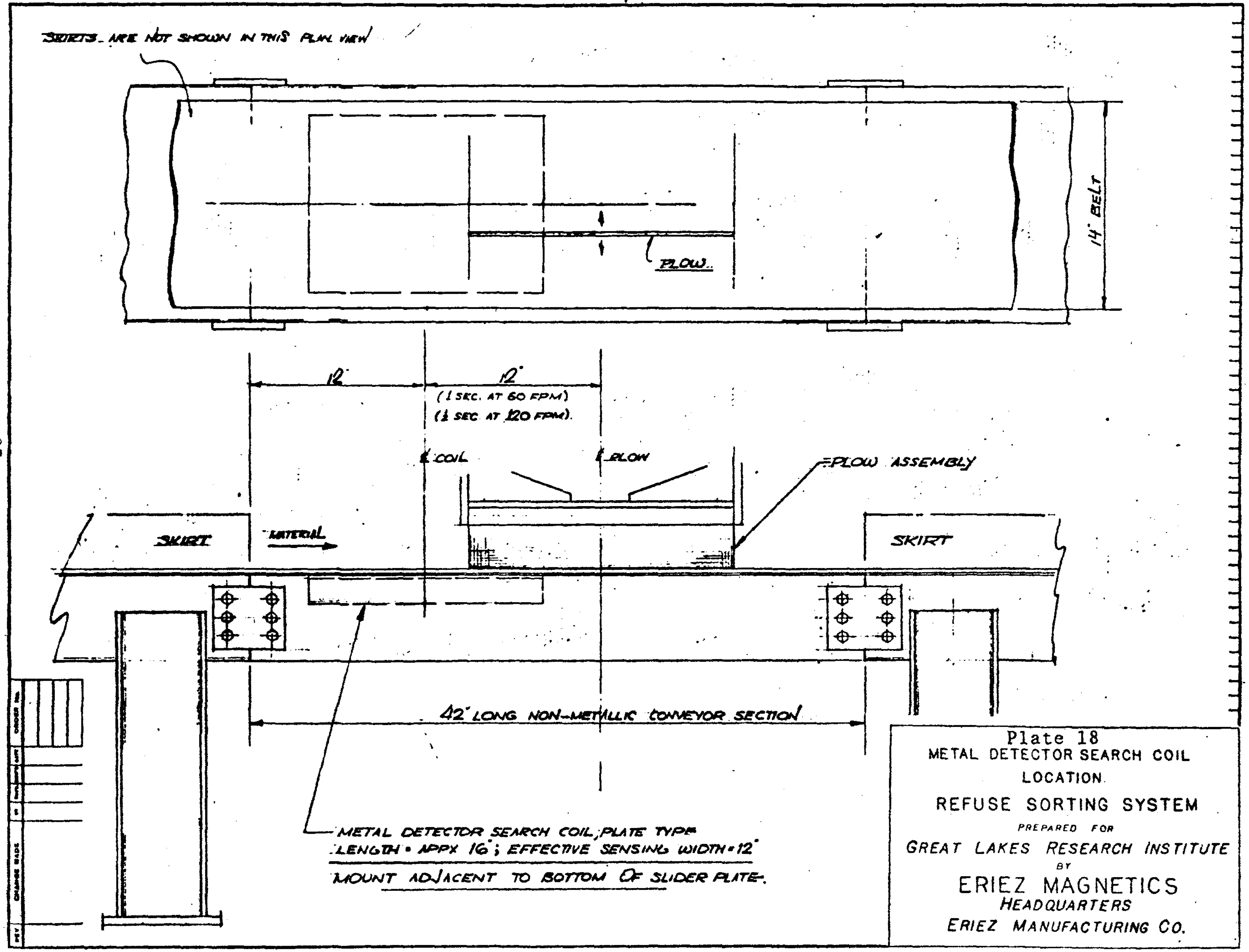

Plate 18
METAL DETECTOR SEARCH COIL LOCATION.
REFUSE SORTING SYSTEM
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BY
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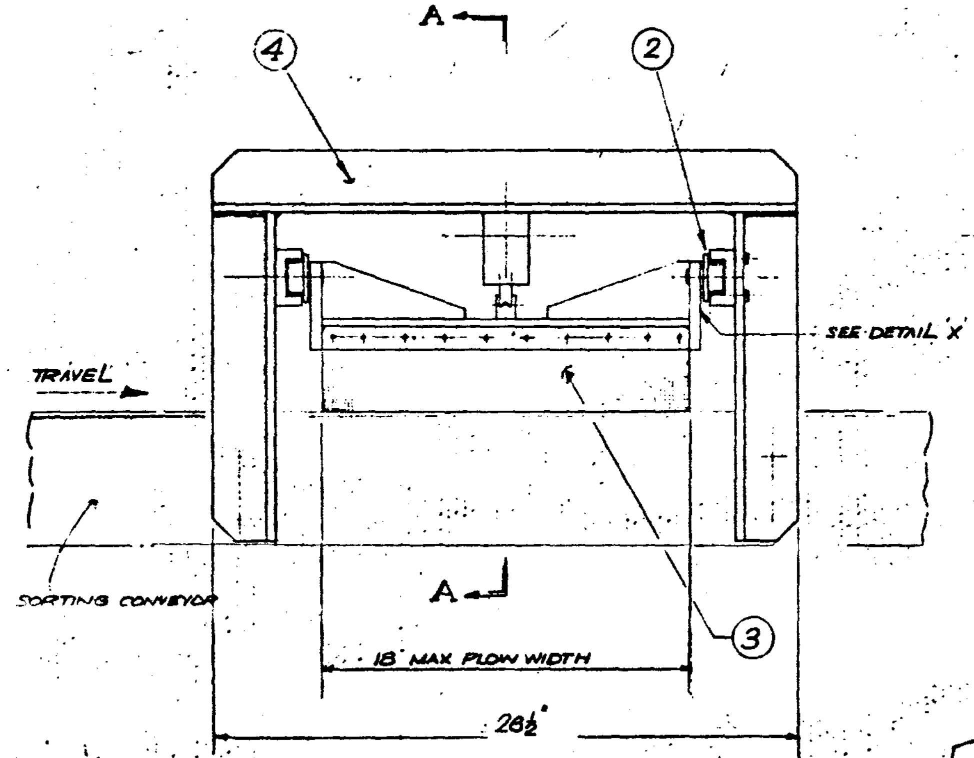
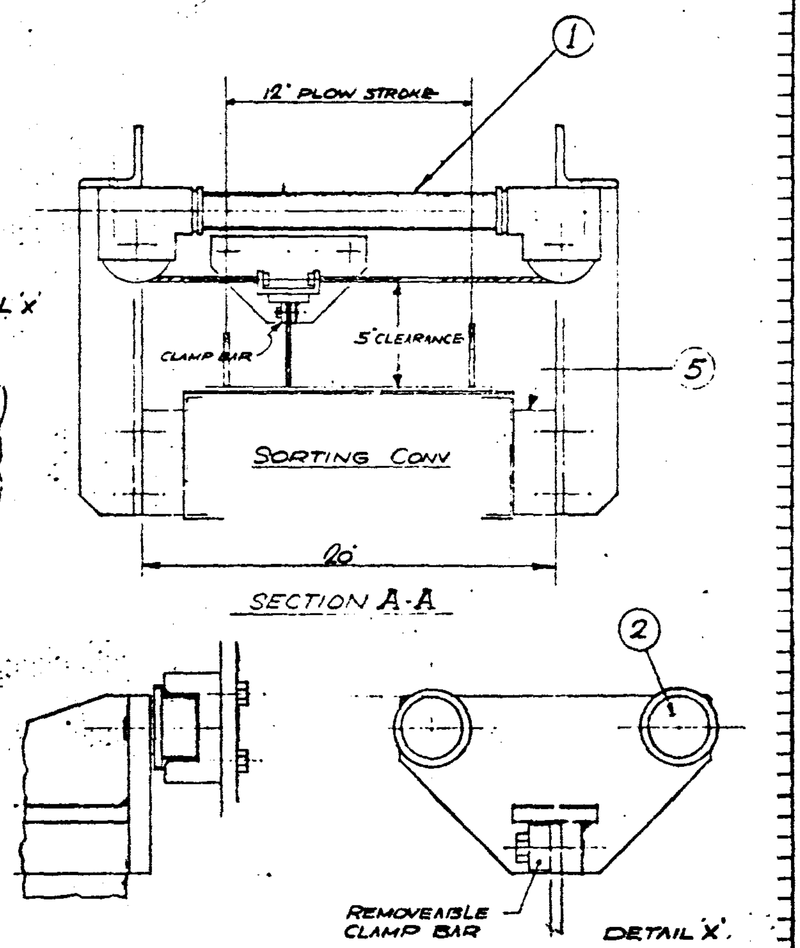
HEADQUARTERS
ERIEZ MANUFACTURING CO.

<u>METAL DETECTOR COIL</u> - PLATE 18 ABOVE

Detection and rejection arrangements of the type necessary for this sorting system always require on-the-job initial adjusting and tuning. The actual mounting position of the coil can be fixed, but because the conveyor belt will have a variable speed, it will be necessary to reset the detector coil with belt speed changes. A control box is to be furnished with the coil and it contains the necessary adjustments to tune the detector coil strength and to set the time lag of the signal to the plow that follows the coil.





NOTES:

1. 12" STROKE, 1½" BORE, CABLE AIR CYLINDER TOL-O-MATIC, INC.
2. FLANGED 1" O.D. CAM FOLLOWER ORANGE ROLLER BEARING CO., INC.
3. PLOW - ¼" THICK REINFORCED NEOPRENE
4. FRAME - 3/8 x 3 x 3 STEEL ANGLE
TRACK - HARDENED STEEL
SUPPORT BARS - STEEL
5. SPACERS - 2" THICK WOOD.

Plate 19

PLOW FOR METALLICS REJECTION

REFUSE SORTING SYSTEM

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HEADQUARTERS

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PLOW FOR METALLIC REJECTION - PLATE 19 ABOVE

Discharge of metallics will be over both sides of the belt. The plow (upon signal from the detector coil control box) will move across the belt and remain there until it receives another signal to return. Both directions of plow travel are rejection strokes, so that the metallics container under this section of the conveyor must be wide enough to receive both these discharges.

If the plow receives a second signal during its travel across the belt, it will immediately return to ensure that no metallics get past this position.

Maximum plow width is 18 inches. The speed of the belt conveyor will determine whether a narrower plow can be used. Assuming a 60 fpm (1 fps) belt velocity and a time of one-third second for the plow to travel across the belt, a 12-inch-wide plow will suffice. Only the minimum width plow necessary to ensure that no metallics can get by the rejection station should be used. In this way, the discharge of nonmetallics along with metallics will be minimized.

Plate 19 above lists the main components of the plow assembly.

The air cylinder is to be furnished with all necessary valves, filters, etc., to make only a connection to the 75- to 150-psi air source necessary.

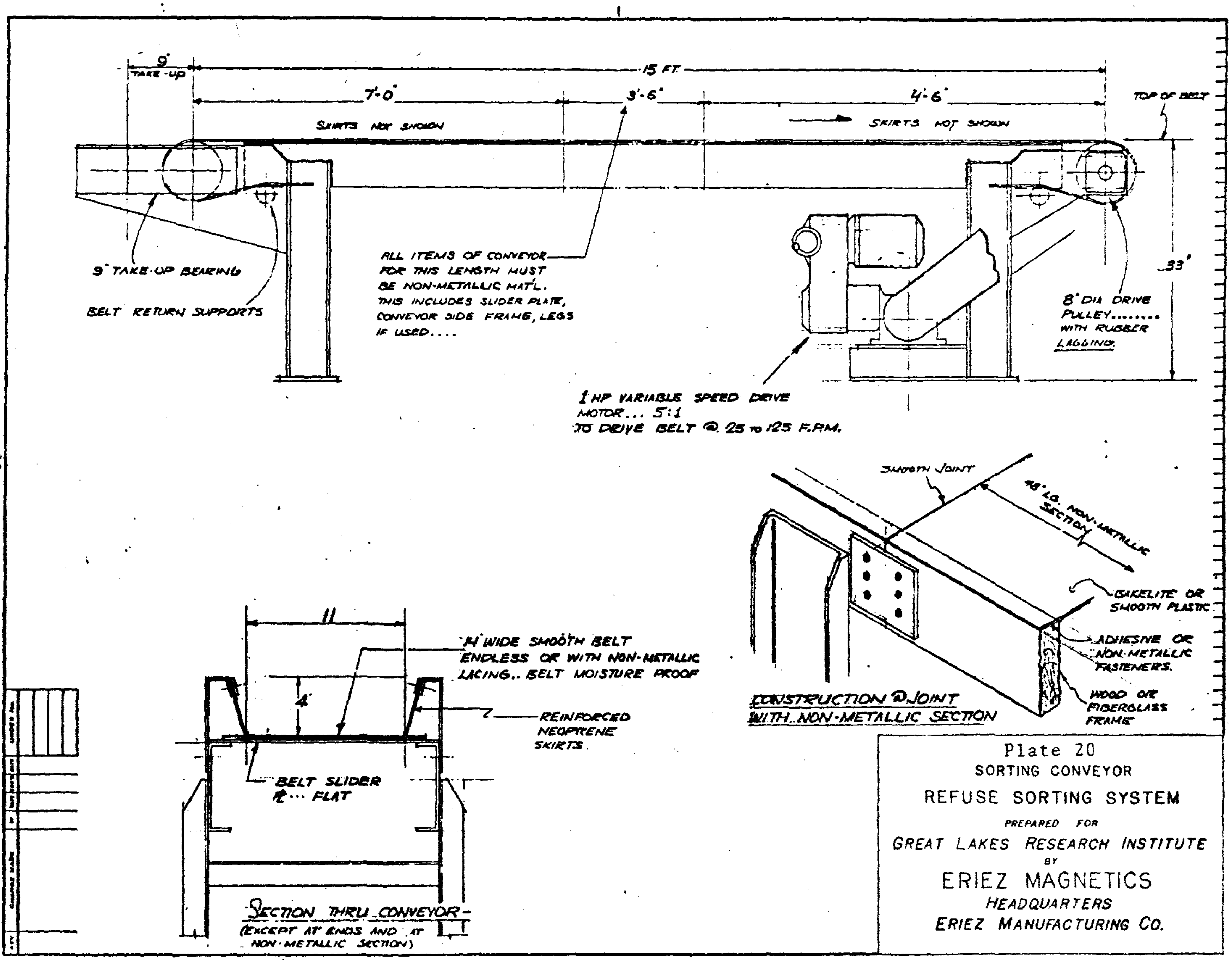

Plate 20
SORTING CONVEYOR
REFUSE SORTING SYSTEM
PREPARED FOR
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ERIEZ MANUFACTURING CO.

SORTING CONVEYOR - PLATE 20 ABOVE

Material burden is minimal and can be ignored in conveyor construction design. Most important to successful operation of the system is a conveyor construction which allows easy and quick adjustments to the various allied assemblies.

The belt is 14 inches wide and has a smooth surface. A teflon-coated belt is recommended. The belt should be endless or laced with nonmetallic lacing.

The skirt assemblies should be short (approximately two feet) sections and arranged so that no material being conveyed can snag and hang up at the joints of skirt sections.

Overall construction will be per Plate 20, but all drawings covering this system should be studied so the conveyor manufacturer can fully understand what is expected.

The head pulley is eight inches in diameter and should be rubber lagged. The drive motor is 220/440 volts, AC, 60 cycle.

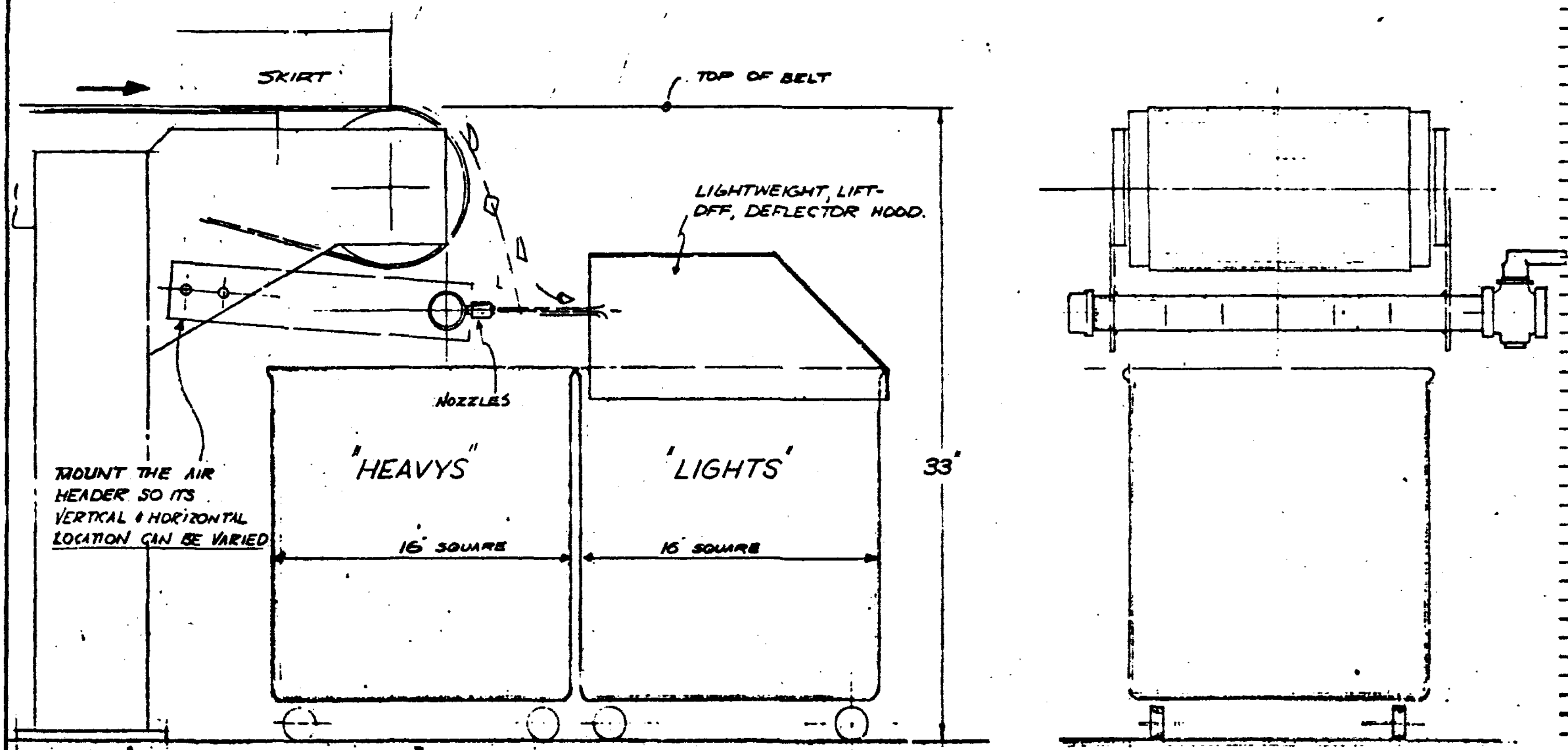

Plate 21
AIR CLASSIFIER
REFUSE SORTING SYSTEM
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ERIEZ MANUFACTURING CO.

AIR CLASSIFIER - PLATE 21 ABOVE

This area, like the other sorting functions of the system, will require "tuning" to the conveyor speed and to material being handled. The air blast header pipe should be mounted so that it can be moved horizontally and vertically and tipped. The hopper (container) positions will require some changing to find their most efficient separation location.

Air for the classifier is 75 to 150 psi and is from the source supplying the plow cylinder.

SECTION VIII: COST ANALYSIS

Total projected costs for the three-year funded period of the solid waste prototype project herein described are $688,600. Of this amount, $172,070 is projected as funds to come from the resources of the applicant. The remaining projected $516,530 are funds which would be requested from the Environmental Protection Agency. Cash flow has been determined as follows:

	Total	First Year	Second Year	Third Year
Amount from Applicant's source	$172,070	$114,870	$ 30,050	$ 27,150
Amount requested from EPA	516,530	344,820	90,170	81,540
TOTAL	$688,600	$459,690	$120,220	$108,690

The First-Year projected costs include approximately $250,000 start-up and construction costs.

SECTION IX: REFERENCES

With the exception of numbers 34, 38, and 41, all references have been verified and restyled by the Office of Solid Waste Managment Programs, U.S. Environmental Protection Agency.

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Section X: Appendices

APPENDIX A

TYPICAL COMPOSITION OF A COMPOSITE MUNICIPAL REFUSE (18)

PERCENTAGE BY WEIGHT

garbage	15%	brush*	1.5%
tin cans	5%	greens*	1.5%
other metals	2%	ripe leaves	5.0%
glass	2%	wood*	2.4%
stone, ceramics	1%	leather*	0.5%
ashes, dirt	5%	rubber*	0.6%
paper	54%	plastics*	0.7%
rags	0.6%	oils, paint*	0.8%
grass*	4.0%	linoleum*	0.1*

*These categories have been taken from an expanded table in the same source document. Their inclusion here accounts for the failure of this breakdown to total exactly 100%.

APPENDIX B

SELECTED CENTERS OF RELEVANT TECHNOLOGY

NAME AND CITY	TECHNICAL COMPETENCE
Visited by members of the project:	
Altoona Composting Plant Altoona, Pennsylvania	Composting of municipal solid wastes (see page 18)
B. J. Fibres, Inc. Santa Anna, California	Fiber reclamation from fiber products
Black Clawson Company Middletown, Ohio	Fractionation of municipal solid wastes (see page 18)
Bureau of Mines College Park, Maryland	Pyrolysis of solid wastes (see page 19)
Clean Steel, Inc. Long Beach, California	Steel recovery from junk cars (see page 7)
Garden State Paper Company Pomona, California	Newsprint manufacture from recovered fiber (see page 18)
Hercules, Inc. Wilmington, Delaware	Composting and pyrolysis of solid wastes (see page 19)
Los Angeles By-Products Los Angeles, California	Tin can recovery from landfills (see page 9)
Public Works Department Madison, Wisconsin	Preparation of solid wastes for open landfill (see page 15)
Stanford Research Institute Irvine, California	Dry separation of solid wastes (see page 23)
USDA Forest Products Laboratory Madison, Wisconsin	Manufacture of paper from fiber recovered from solid wastes
Other Relevant Centers:	
The Aluminum Association New York, New York	Incineration and pyrolysis of solid wastes with mineral recovery (see page 19)

NAME AND CITY	TECHNICAL COMPETENCE
Battelle Memorial Institute Columbus, Ohio	Market identification for materials recovered from solid wastes
Bureau of Mines Pittsburgh, Pennsylvania	Mineral recovery from incinerator residues (see page 19)
Combustion Power, Inc. Menlo Park, California	Production of electricity from solid wastes (see page 19)
Metropolitan Waste Conversion Corp. Houston, Texas	Composting of municipal solid wastes (see page 17)
Monsanto's Enviro-Chem System St. Louis, Missouri	Pyrolysis of solid wastes (see page 19)

APPENDIX C

ALTERNATIVE METHOD OF METALLIC/NONMETALLIC SEPARATION

As an alternative for the separation of metallic particles from non-metallic particles, the following system is suggested.

It is hoped that, because of the limitation on the metal detecting area, this separation system will be more effective.

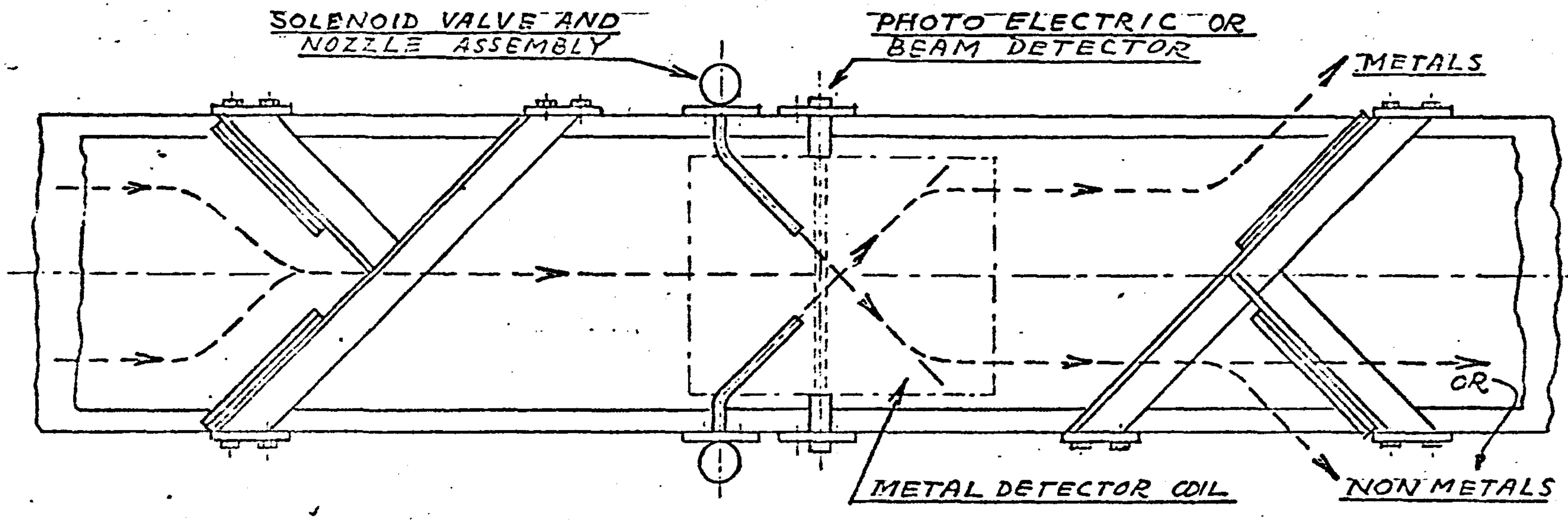
After the separation of ferrous particles, the remaining part of the feed material will be narrowed on the belt. In a limited area, depending on the detection of a metal or non-metal particle, air jets over the solonoid valves can be controlled so that metals and non-metals will be separated to either side of the sorting conveyor.

The plate-type search coil of Applied Electronics can be the metal detector if sensitivity adjustment permits. Otherwise the Proxi-Tron Electronic Proximity Detector of Automation Devices, Inc.,or the Proximity Sensing Head of Electro Products Lab, Inc., may be used.

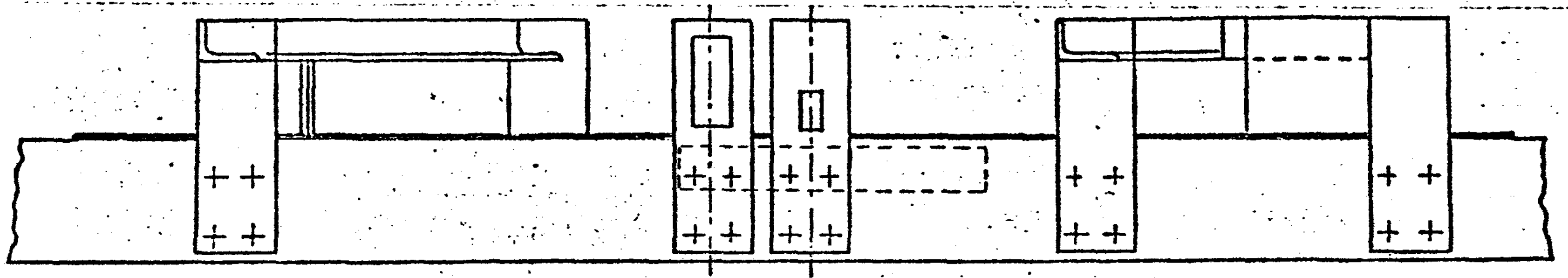
For particle detection, the Lite-Ton Photoelectric or Beam-tron proximity detector of Automation Devices, Inc.,may be used.

On the solonoid valves, for more economical and dependable operation, Magnelatch types are recommended.

For more reliable operation solid-state-type relays should be selected.

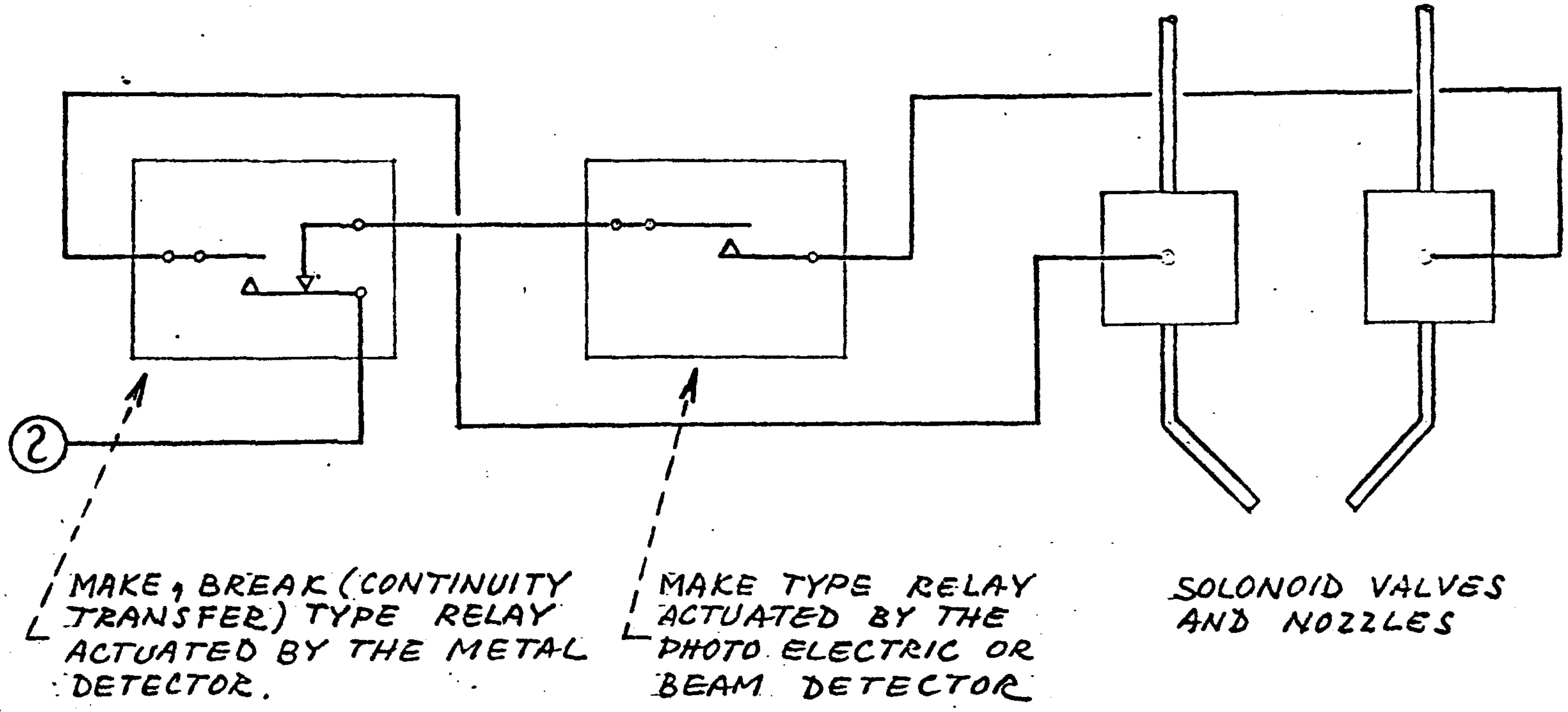


PLAN VIEW OF SORTING CONVEYOR BETWEEN MAGNETIC DRUM & AIR CLASSIFIER



SOLID WASTE SORTING SYSTEM

GREAT LAKES RES. INST. HK



RELAY DIAGRAM

SOLID WASTE SORTING SYSTEM

GREAT LAKES RES INST. HK