# Selective Electronic Mineral Sorting to 1972

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# PREFACE

As a contribution to the *Mineral Processing Handbook* being prepared by the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), for publication 1974, information on electronic sorting was gathered by the author over a number of years, cleared by the principal equipment developers and submitted to the Handbook editors in January 1972.

An opportunity was thus afforded for the most complete roundup of electronic sorting information to date. The currently most active groups in equipment development are Gunson's Sortex Limited, Ore Sorters (Canada) Limited, Colonial Sugar Refining Company Research Laboratories, the Royal School of Mines, and United Kingdom Atomic Energy Authority.

Because the principles involved are not well known to the mineral industry, and because the subject is topical, it seemed appropriate that an early release of this information be made to the public. The principal developers agreed to this proposal and have examined and corrected the data used, which has been expanded and updated for this publication.

Sources are listed in Table 1-A and in References.

Ottawa, May 1972                                                    R. A. Wyman

# INTRODUCTION

As expressed by Arthur F. Taggart[1], concentration methods "are based upon utilization of some property in which the intermingled severed minerals differ either in kind or degree, to effect a differential response to some impulsive force."

He goes on to state that generalizations common to all concentration methods include: (i) "Concentrate and/or tailings should be taken out of the mill stream at as coarse a size as is consistent with maintenance of the desired grade of concentrate; (ii) concentrating processes other than flotation all depend upon the existence of an appreciable difference in some physical property of the valuable mineral and gangue; (iii) concentration by physical means can, in general, be performed at any size at which the constituent minerals are sufficiently severed to justify designation of individual pieces as concentrate and/or tailings; (iv) the capacity of a concentrating machine or operation increases with increase in size of feed particles."

The simplest, most direct, and sometimes the most effective method of concentration is sorting by eye and hand. Hand sorting has been practised since antiquity. The Taggart precepts for concentration apply to it. In the modern mineral processing context, however, hand sorting can rarely be economically justified.

The elements involved in hand sorting are eyes, brain, and hands. It was inevitable that mechanical substitutes for these elements would be devised. For machine sorting these elements became, (i) a method of presentation or of feeding, (ii) a method of distinguishing one mineral or grade of mineral from another, (iii) a method of comprehending and utilizing this information, and (iv) a method of separating one mineral from another.

Sorting by machine became feasible with the advent of a means of duplicating some of the functions of the brain. The means was provided by modern electronics, so, for this reason, machine sorting is usually referred to as "electronic sorting." The similarity between mixtures of mineral particles and such agricultural products as coffee beans, peanuts, and peas is readily apparent. The replacement of hand sorting by machine sorting in the agricultural field was, in fact, well established before similar mineral sorting devices came into use. Since their introduction after the Second World War, many thousands of food sorting machines have been successfully employed.

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Although contemporary in conception, mineral sorting devices have had a much longer evolutionary period than food sorters. The first true mineral sorter was that devised in 1946 by a group of scientists at the Canadian Mines Branch, led by C. M. Lapointe. This was an electronic method of detecting and isolating uranium-bearing pieces of rock. The system was tested at Port Radium, Northwest Territories, and at Port Hope, Ontario, in 1947 and 1948[2,3]. In the late 1940's A. M. Gaudin[4,5], Massachusetts Institute of Technology, and F. E. Senftle[4,5], United States Geological Survey, combined to develop a method of separation

### Table 1
### Electronic Sorting Developments since 1960

| Period | Source* | Development |
|---|---|---|
| 1960- | 1 | Experiments with X-ray fluorescence on metallic ores. |
| 1963 | 1 | Experiments with Random Stream sorting by reflected light. |
| | 1 | Random Stream Translucent Materials Sorter. |
| | 1 | Quantitative Photometric Materials Sorter. |
| | 2 | Food Sorter applied to marl from gypsum. |
| | 2 | Food Sorter installation by Canadian Rock Salt Company. |
| 1964 | 3 | Diamond Sorter. |
| | 4 | Optical Sorter for limestone. |
| | 4 | Electro-Mechanical Selector for 0.75 to 0.125-in. (19.0 to 3.2-mm) feed. |
| | 16 | Sorting Apparatus. |
| 1965 | 2 | 621M Optical Sorter for 0.75 to 0.25-in. (19.0 to 6.4-mm) feed. |
| | 1 | Model 10 High-Voltage Conductivity Sorter for dry feed. |
| | 5 | X-ray Fluorescence Sorter. |
| | 6 | Study of X-ray fluorescence for copper ores. |
| 1966 | 2 | 811M Optical Sorter for 6 to 2-in. (15.2 to 5.1-cm) feed. |
| 1967 | 2 | 711M Optical Sorter for 2 to 0.75-in. (5.1 to 1.9-cm) feed. |
| | 15 | Gamma-ray potash selector. |
| 1968 | 2 | XR-21 Diamond Sorter for 0.375-in. to 14 mesh (9.5 to 1.2-mm) feed. |
| | 2 | XR-11 Diamond Sorter for 1.25-in. to 7 mesh (31.7 to 2.8-mm) feed. |
| | 1 | Model 10 Low-Voltage Conductivity Sorter for dry or damp feed. |
| | 7 | Oscillator-Audio system for metallic ores. |
| | 8 | X-Septa system for shale from coal. |
| | 9 | Asbestos Ore Sorter. |
| 1969- | 10 | Slurry presentation, X-ray transparency diamond Sorter. |
| 1972 | 10+2 | Ultraviolet fluorescence Sorter. |
| | 10+2 | Feasibility of radiometric sorting for South African ore. |
| | 10 | Experiments with high-speed, small-particle separation. |
| | 9 | A conductivity sorter. Fluorescence sorter development. |
| | 11+2 | Optical system for uranium ores. Translucency Sorter. |
| | 12 | Mineral Sorter for small particles. |
| | 1 | Model 12 Photometric Sorter. Model 13 Photometric Sorter. |
| | 9 | Fluorescence Sorter. |

*See Table 1-A.

based on induced radioactivity. By 1953, Newman and Whelan[6], National Coal Board, England, had worked out a photometric method for separating bright from dull coal, a method that was also effective for separating a variety of non-metallic minerals from associated gangue. A similar system, using polarized light, was advocated for coal by Edmonds[7], also of the National Coal Board, England.

In the mid-1950's, L. Kelly and J. Hutter, of Bicroft Uranium Mines, Canada, set out to apply their own ideas to the problem of uranium concentration by machine sorting. The "K and H Radiometric Sorter," patented in 1958, was made practical by the "Single Row Feeder," and the "Pilot Operated Valve," invented by the same team. A number of successful commercial installations[8] followed. Kelly and Hutter are also to be credited with introducing the "Random Stream" or the single-layer ribbon presentation system, a contribution to the development of high-capacity equipment.

It was natural that these new techniques should catch the attention of the diamond interests. In 1960, a method for isolating gem-quality stones, based on their ability to reflect and transmit light, was described by Linari-Linholm[9] of the Diamond Research Laboratory, Johannesburg.

Since 1960, development of mineral sorting devices has been more rapid. Two groups have been particularly active, Ore Sorters (Canada) Limited and Gunson's Sortex Limited. The former took over the Kelly and Hutter patents in 1964 and also retained the expertise of these inventors. The main developments since 1960 appear in Table 1, and the chief sources of sorting information and equipment are given in Table 1-A.

## Table 1-A
### Sources of Sorting Information

| Designation | Source |
|---|---|
| 1 | Ore Sorters (Canada) Limited. |
| 2 | Gunson's Sortex Limited. |
| 3 | Ateliers de Constructions Electriques de Charleroi (or A.C.E.C.). |
| 4 | Gromax Inc. |
| 5 | Mines Branch, Ottawa, Canada. |
| 6 | Applied Research Laboratories Inc. |
| 7 | International Sorting Systems Corp. |
| 8 | Schwarz Mining and Industrials Limited. |
| 9 | Colonial Sugar Refining Company Research Laboratories. |
| 10 | The Royal School of Mines Sorting Research Group. |
| 11 | United Kingdom Atomic Energy Authority (or UKAEA). |
| 12 | Electric Sorting Machine Company. |
| 13 | Newman and Whelan[6]. |
| 14 | Linari-Linholm[9]. |
| 15 | Coughlin and Ault[17]. |
| 16 | Mathews[10]. |
| 17 | deL.E.Edmunds[7]. |

# MECHANICS

## PRESENTATION

Presentation or feeding is the means for orienting and delivering the feed to a "sensing zone" in such a way that proper inspection and assessment may take place.

### Requirements

Sorting systems deal with mineral particles on an individual basis, therefore high throughput is necessary. A presentation system must withdraw feed from some bulk source, orient the particles on a sufficiently separated basis to allow examination, and carry the particles through the sensing position to the separation position. The irregular shape of rock particles works against the efficient accomplishment of this task; this has inspired a number of ingenious presentation devices. The actual method of passing the feed through the sensing position is largely dependent upon the sensing system employed and on the geometry of the equipment. Means must be provided for positioning and spacing pieces in the sensing zone to ensure proper individual assessment.

*Size of feed*

The minimum size of particle which may be practically sorted at present is about 16-mesh (1.0-mm). There is no mechanical limit on maximum size. Maximum size is determined in each case by the metallurgical results required, by liberation considerations, and by overall economics.

The number of pieces per ton of feed will depend on the size of piece. This is illustrated in Table 2 for sulphide copper ore.

### Table 2
### Effect of Particle Size*
### (Sulphide copper ore)

| Size (sq mesh) | Average weight per piece (lb) | Average number of pieces per ton |
|---|---|---|
| Plus  4-in. | 8.713 | 230 |
| 4 to 2-in. | 2.040 | 980 |
| 2 to 1-in. | 0.122 | 16,420 |
| 1 to 0.75-in. | 0.031 | 64,935 |

*Courtesy of Ore Sorters (Canada) Limited.

Design factors also play a part in the size of feed which may be processed. In common with other mechanical systems, sorting equipment must be rugged enough to handle the largest and heaviest pieces of feed expected. A large percentage of feed smaller than the design size therefore tends to become uneconomic. At the same time, sensing and electronic systems must be provided to make decisions at a specific rate. This means that greatest efficiency will be achieved with the largest pieces that can be handled at this rate. In addition, the design of some presentation.

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systems places a relatively close tolerance on feed size. For these reasons greater efficiency and throughput per machine usually ensue from presizing feed.

*Pretreatment of feed*

In any mining operation, blasting and subsequent handling invariably produce particles ranging down to those too small for practical sorting. A number of size fractions, suitable as sorting feeds, may be produced by screening. Material smaller than the smallest size that may be practically sorted should be isolated because such undersize particles may not be detected by the sensing system. Conversely, because of close packing of feed, undersize might be detected and cause undesired removal of a larger piece. Regardless of its nature, the feed should be free of adhering fine powder so that the surfaces can be clearly observed by the sensing system. Therefore, either an air or a water rinse is usually employed.

For dry sorting systems such as high-voltage conductivity, the feed must be dry. It is usually found preferable to wash and drain the feed prior to drying because adhering fines tend to retain moisture. Occasionally, a chemical pretreatment may be used, e.g., to improve a photometric property, or to enhance conductivity. Washing prior to such treatment presents clean surfaces, and less chemical will be required.

## Types of presentation

Presentation techniques fall roughly into two classes: 1) in-line, where the pieces are caused to move in single file, and 2) single-layer, where a band of pieces of appropriate width but only one layer in depth is used, although one or two unusual variations have evolved. The single-layer method offers a great advantage in capacity per unit. When the objective is to scan a particle from all sides, however, the in-line method is normally used because it provides free fall in air.

*In-line systems*

With one or two exceptions, the objective of in-line systems is to present the particles for scanning from all sides. The systems usually include acceleration from rest in a hopper to closely spaced, single-file delivery with a controlled trajectory through the sensing and the separation points. With pieces up to about 1 inch in size, such a system is relatively simple to arrange. With larger pieces the shape factor tends to cause irregular feed unless special use is made of friction, inertia, and centrifugal force. Multiple unit devices may be designed by arranging for several streams to draw feed from the same hopper and incorporating the whole in a single superstructure.

Types of in-line presentation systems referred to in Table 3:

A. *Flat belt* — A flat conveyor belt drawing feed from a hopper with some simple device such as a slide for aligning the pieces; *see* Figure 1.

B. *Grooved belt* — A comparatively thick and narrow conveyor belt with a channel cut into the top for carrying pieces in a single line. Feed is drawn from a hopper, usually via a vibrating feeder, and a simple device such as a v-slide is used to guide the pieces into the groove; *see* Figure 2. Multiple units may be employed.

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**Table 3**
**In-line Systems**

| Feed Size Range | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 4 to 20 mesh<br>(4.8 to 0.85-mm) | 2 | B | Diamonds | Model 414 D |
| 0.31 to 0.031-in.<br>(8.0 to 0.8-mm) | 3 | A | Diamonds | Special design |
| 0.375 to 14 mesh<br>(9.5 to 1.2-mm) | 2 | B | " | Model XR 21 |
| 4 to 10 mesh<br>(4.8 to 1.7-mm) | 12 | C | General | Model G 3800 R |
| 0.75-in. to 7 mesh<br>(19.0 to 2.8-mm) | 2 | C | ... | Model 962 M |
| 0.75 to 0.25-in.<br>(19.0 to 6.4-mm) | 2 | B | " | Model 621 M |
| 2 to 0.75-in.<br>(5.1 to 1.9-cm) | 2 | E | " | Model 711 M |
| 7 to 0.75-in.<br>(17.8 to 1.9-cm) | 9 | D | " | Designed for asbestos |
| 6 to 2-in.<br>(15.2 to 5.1-cm) | 2 | E | " | Model 811 M |
| 8 to 2-in.<br>(20.3 to 5.1-cm) | 5 | A | Heavy elements | Special design |
| 10 to 2-in.<br>(25.4 to 5.1-cm) | 1 | E | Radiometric | Model 6 |
| 10 to 2-in.<br>(25.4 to 5.1-cm) | 5 | A | " | Special design |

*See Table 1-A; **See text.
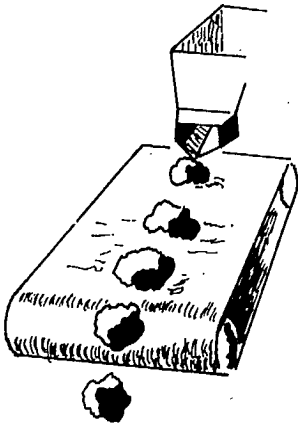


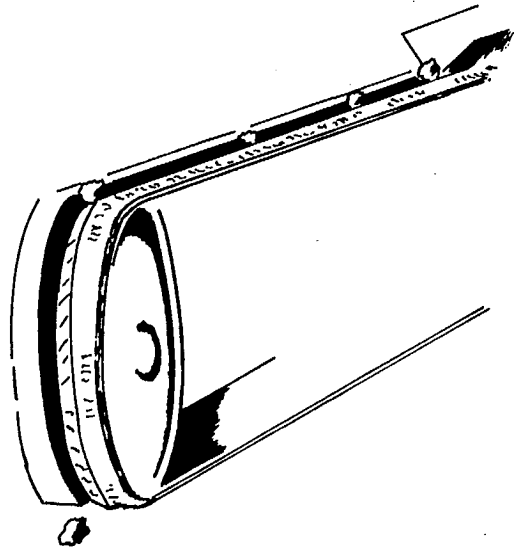Figure 1. Flat-belt, single-line



Figure 2. Grooved-belt, single-line

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C. *Slide* — A trough or slide set at an angle steeper than that of repose down which pieces gravitate in line. Feed is usually moved from a hopper via a vibrating feeder; *see* Figure 3. Slide dimensions must be consistent with feed size to be treated. These are usually multiple-unit systems.

D. *In-line rolls* — Two contra-rotating cylinders of predetermined size and set at a predetermined slope to accommodate specific feed sizes. Material is usually moved from a hopper, via a vibrating feeder, onto the upper end of the cylinders; *see* Figure 4.

E. *Disc-belt* — Single, or tandem, vibrating feeders draw from a hopper and deliver to a rotating disc, or to a flat cone. Feed pieces travel to the periphery by centrifugal force and a retaining wall causes them to form a line. This line of pieces discharges onto a flat conveyor belt at a speed equal to the travel rate of the belt; *see* Figure 5. This is usually employed for large feed, i.e., plus 2-inch (5.1-cm).

*Single-layer systems*

Single-layer systems require removal from a hopper and even distribution across a delivery vehicle that moves the feed through sensing and separation points. The objective is to greatly increase capacity per unit by condensing multiple in-line presentation into one continuous stream. Therefore, the stream may be visualized as many adjacent single lines so closely associated that they touch. Such close association permits examination from above, below, or from both but not from all sides.

Single-layer systems are best for plus 1-inch (2.5-cm) pieces but may be applied to finer pieces where circumstances warrant. A feature of some systems, notably those of Ore Sorters (Canada) Limited, is the tandem vibrating feeder. Feeder No. 1 draws from the storage hopper and discharges onto Feeder No. 2. This second feeder incorporates grizzly bars which remove fines and aid in spreading the feed to a stream of the desired width.

Table 4 indicates single-layer systems currently in use. The various types indicated are briefly described in the following text.

**Table 4**
**Single-layer Systems**

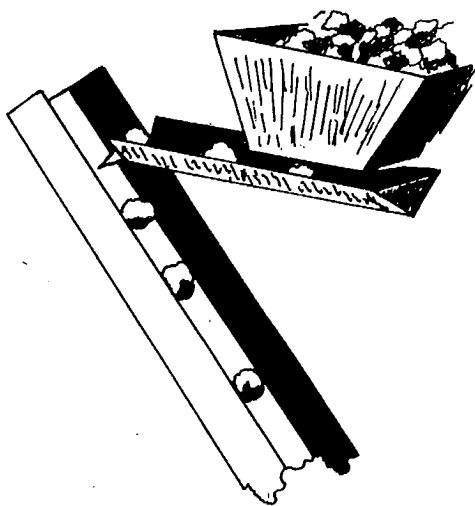| Feed Size Range | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 1.25-in. to 7 mesh (32.0 to 2.8-mm) | 2 | F | Diamonds | Model XR 11 |
| 5 to 0.5-in. (12.7 to 1.3-cm) | 1 | F | General | Model 12 |
| 10 to 0.75-in. (25.4 to 1.9-cm) | 1 | G | Conductance | Model 10 |
| 7 to 1-in. (17.8 to 2.5-cm) | 8 | F | Coal | Watson X-Septa |

*See Table 1-A; **See text.

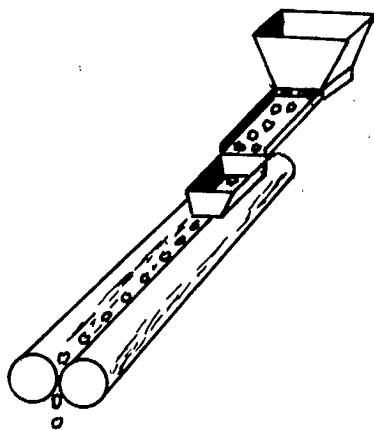**Figure 3. Slide, single-line**
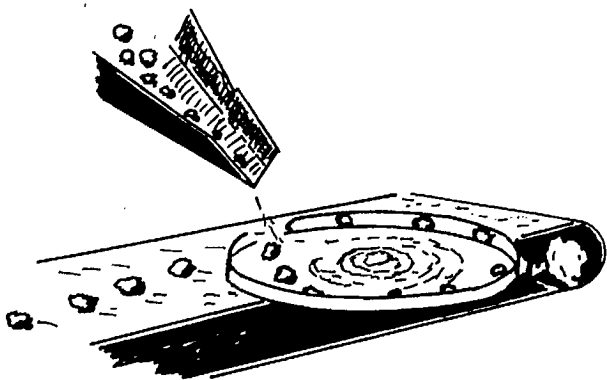


**Figure 4. In-line rolls, single-line**



**Figure 5. Disc-belt, single-line**
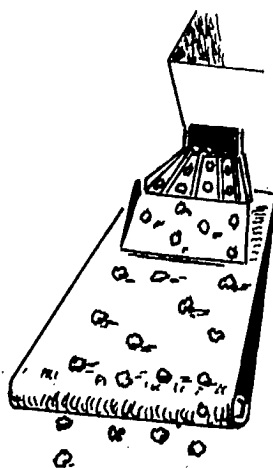


**Figure 6. Flat-belt, single-layer**

F. *Flat belt* — A flat conveyor belt drawing feed from a hopper via single, or tandem, vibrating feeders, and a spreader plate; *see* Figure 6.

G. *Slide* — Tandem vibrating feeders to draw feed from a hopper and deliver it to a slide so sloped that the particle stream is carried through the sensing and separation points; *see* Figure 7.

*Novel arrangements*

Several ingenious devices have been developed. All are variations of the in-line method, usually to produce a multi-channel operation. Four such systems are:

A sectionalized conveyor system was developed by Gromax, Inc.,[10] to handle 12 to 4-inch (30.5 to 10.2-cm) limestone. The system is based on a conveyor composed of 4-inch (10.2-cm) wide steel plates attached to the drive chains. Feed is supplied from a hopper, via a belt, to one side of the conveyor. The opposite side is occupied by special "boots," one for each plate. These boots may be diverted on signal to provide separation; *see* Figure 8.

A rotary variation has been built into the Select-Ore Sorter developed by International Sorting Systems Corp. A separate machine is required for each size range, e.g., for 2 to 1-inch (5.1 to 2.5-cm). The correct feed fraction is delivered by belt conveyor and drops through a top opening in the sorter to the centre of a rotating impeller that has curved channels similar to the impeller of a centrifugal pump. Feed is randomly distributed into the channels and moves outward by centrifugal force toward the periphery. Sensing and separation are accomplished at the end of each channel; *see* Figure 9.

A vibrating multiple-trough system designed by Edmonds[7] for the National Coal Board, England, moves feed in lines over the sensing points and through the separation points. At the separation points, the troughs are divided into lower and upper channels. The lower channels are shorter than the upper; this permits separated material to be discharged onto separate belts; *see* Figure 10.

A patent[20] granted to the Royal School of Mines, England, covers presentation of feed in slurry form through rectangular channels which may be single or be compartmented; *see* Figure 11.

## SENSING

The techniques applied for detecting a property, or combination of properties, that will distinguish specific mineral pieces from others in a mineral assemblage are discrimination, or sensing, techniques.

Because mineral pieces are complex it may be necessary to sense more than one property, or a ratio of specific characteristics.

A sensing device must recognize the designated distinguishing features and produce an electrical signal to indicate that it has done so.

Since sensing recognizes the specific characteristics of individual pieces, sufficient liberation must be provided in the feed to allow such discrimination.
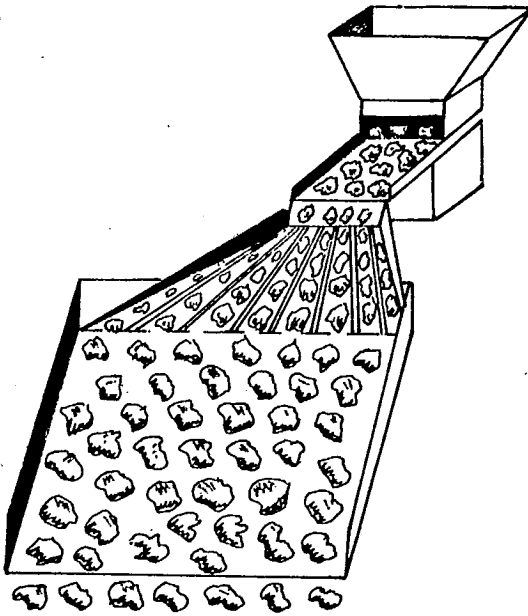
Figure 7. Slide, single-layer
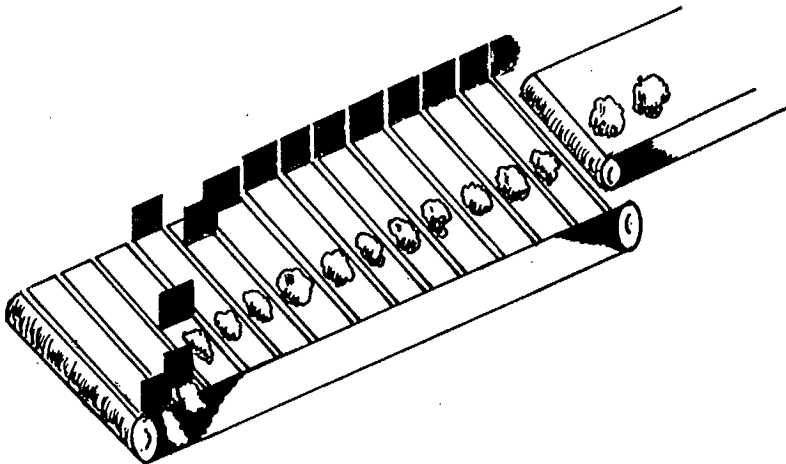


Figure 8. Sectionalized conveyor, single-line
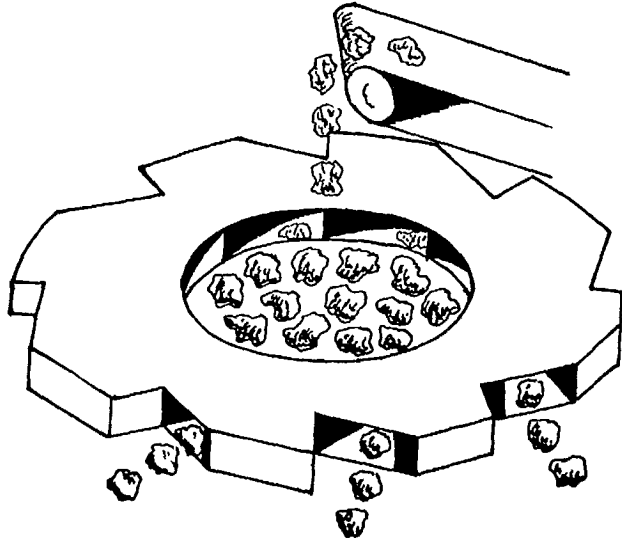
**Figure 9. Rotary, multiple-line**
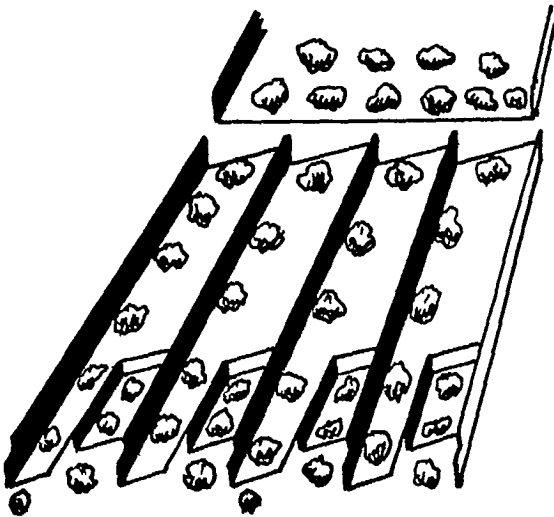


**Figure 10. Chute, multiple-line**

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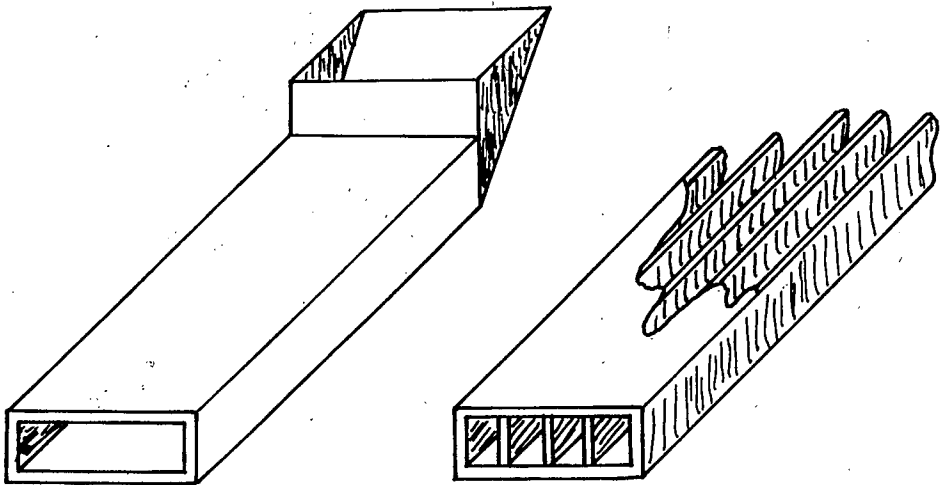
**Figure 11. Slurry**

## Properties that can be sensed

Before a sensing system becomes operative, a detectable property and a device for discriminating that property must exist, A perspective on sensing may be achieved by relating it to the electromagnetic spectrum (Figure 12). Devices have been developed for detection at minus 1-mm wavelengths, and techniques similar to those used in television have been applied.

A summation of the relationship between detectable properties and existing detection devices is provided in Table 5.

**Table 5**
**Relation of Sensing Devices to Sensed Property**

| Property | Sensing Device |
|---|---|
| Natural radioactivity | Scintillation counter and pulse analyzer |
| Induced radioactivity | As above |
| X-ray transparency | As above |
| X-ray fluorescence | Phototube |
| Ultraviolet fluorescence | Phototube |
| Visible reflectance | Phototube |
| Visible transparency | Phototube |
| Differential heating | Infrared scanner |
| High-voltage conductance | Resistance, or current flow network |
| Low-voltage conductance | As above |

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| WAVE LENGTH (millimicrons) | COMPARATIVE UNITS | TYPES | SENSING SYSTEMS |
|---|---|---|---|
| $10^{-3}$ | | GAMMA | Induced beta/gamma activity<br>Induced neutron activity<br>Natural radioactivity |
| $10^{-2}$ | | | |
| $10^{-1}$ | 1 Angström unit | | Fluorescence<br>Transparency |
| 1 | 1 Millimicron | X-RAY | |
| $10^1$ | | | |
| $10^2$ | | ULTRA VIOLET | Fluorescence |
| $10^3$ | Violet(375)<br>Red(750) | VISIBLE | Reflectance<br>Transparency |
| $10^4$ | | INFRA-RED | Differential heating<br>Wave length shift |
| $10^5$ | | | |
| $10^6$ | 1 Millimeter | | |
| $10^7$ | | | |
| $10^8$ | 1 Inch | HERTZIAN<br>(Radar, T.V., Radio) | ? |
| $10^9$ | 1 Meter | | |
| $10^{10}$ | | | |

Figure 12. Sensing and the electromagnetic spectrum

## Sensing Systems

*Radioactive*

*Natural* — Materials (uranium and thorium) which undergo spontaneous decay constitute the naturally radioactive group. They offer a unique and highly distinctive property that is easily detected, so initial development was for sorting ores of this group.

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Alpha, beta, and gamma rays are all produced by natural radioactive emissions. Initial experiments employed gamma-sensitive geiger tubes for high-grade, and beta-sensitive geiger tubes for low-grade ores. Scintillation counters soon replaced the gamma-sensitive geiger tubes. If acceptable capacity per sorting unit is to be obtained, a large scintillation counter must be used because it is possible to expose a piece of rock in a presentation system to a scintillation counter for only a fraction of a second. Well-shielded sodium iodide-thallium, NaI (Tl), crystals, 5-inch (12.7-cm) in diameter and 4-inch (10.2-cm) thick, have proven to measure sufficient counts during a short exposure time to detect natural uranium contents as low as 0.15 lb/ton (0.075 g/kg) in pieces weighing 2 lb (0.91 kg).

In dealing with natural radioactivity, it is necessary to employ an economic cut-off for each piece. A large low-grade piece and a small high-grade piece can contain valuable material in equal amount, therefore, it is necessary to determine the approximate size of each piece and to measure its activity; *see* Figure 13. The information from both sources is integrated by a computing circuit and compared to the cut-off value. An accept signal is provided for all pieces above this value.

*Induced* — Most elements become radioactive if they are bombarded by neutrons. The isotopes so produced are unstable and decay with the emission of beta and/or gamma rays. Each isotope has a specific half-life and the emitted gamma radiation has characteristic energies (Table 6). Neutron activation analysis, based upon this principle, provides a sensitive method for the detection and quantitative determination of a large number of elements.

In applying the above principle to mineral separation, it has been found necessary to introduce supporting devices. A mixture of minerals will contain many elements and it is unlikely that irradiation will produce a response which will sufficiently distinguish the mineral association it is desired to isolate. A pulse-height analyzer may be used to identify the gamma rays emitted in the decay of the irradiated mineral assemblage. It is also possible to use filters to bracket specific wavelengths.
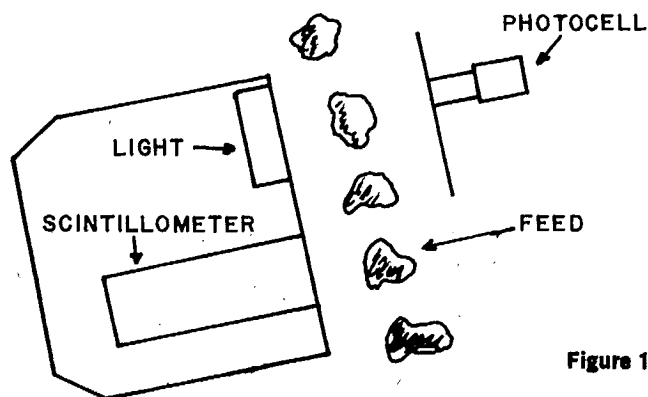


Figure 13. Radiometric sensing

**Table 6**
**Selected Examples of Irradiation Products of Elements***

| Atomic Number | Element | ** | Irradiation Product | Half-Life | Energy Peaks (MeV) | |
|---|---|---|---|---|---|---|
| 9 | Fluorine | F | O 19 | 29.10 sec | 0.20 | |
| 11 | Sodium | F | Ne 23 | 38.00 sec | 0.44 | |
| 12 | Magnesium | F | Ma 25 | 60.00 sec | 0.40 | |
| 13 | Aluminium | F | Mg 27 | 9.50 sec | 0.84 | 1.01 |
| 20 | Calcium | F | K 44 | 22.00 min | 1.13 | |
| 22 | Titanium | F | Sc 50 | 1.80 min | 0.51 | |
| 24 | Chromium | F | V 52 | 3.76 min | 1.43 | |
| 25 | Manganese | T | Mn 56 | 2.58 hr | (0.845) | 1.81 |
| 26 | Iron | F | Mn 56 | 2.58 hr | 0.845 | |
| 27 | Cobalt | T | Co 60$^m$ | 10.35 min | 0.059 | |
| 28 | Nickel | F | Co 61 | 1.65 hr | 0.072 | |
| 38 | Strontium | T | Sr 87$^m$ | 2.80 hr | 0.39 | |
| 40 | Zirconium | F | Zr 89$^m$ | 4.18 min | 0.59 | |
| 48 | Cadmium | T | Cd 111$^m$ | 49.00 min | 0.25 | |
| 50 | Tin | F | Sn 125$^m$ | 9.70 min | 0.33 | |
| 52 | Tellurium | F | Te 131 | 25.00 min | 0.15 | |
| 55 | Cesium | T | Co 134$^m$ | 2.91 hr | 0.127 | |
| 56 | Barium | T | Ba 137$^m$ | 2.60 min | 0.662 | |
| 73 | Tantalum | F | Ta 180$^m$ | 8.10 hr | 0.057 | |
| 74 | Tungsten | T | W 187 | 24.00 hr | 0.48 | 0.68 |
| 79 | Gold | T | Au 197$^m$ | 7.30 sec | 0.28 | |
| 81 | Mercury | F | Hg 199$^m$ | 44.00 min | 0.16 | |
| 82 | Lead | F | Pb 204$^m$ | 67.00 min | 0.38 | 0.90 |

*After Dibbs[11]; **F = 14-MeV neutron activation.
T = 0.025-eV (thermal) activation.

*Gamma-neutron* — Bombardment of a sample with gamma rays will release neutrons. This may be regarded as the reverse of activation by neutron bombardment. The classic example is emission of neutrons from beryllium when irradiated by gamma rays of energy greater than 1.66 MeV. This provides a satisfactory basis for discrimination. The gamma-neutron threshold energy for beryllium is significantly less than other elements except deuterium[22]. Neutrons emitted may be detected by counters having a high neutron-to-gamma ray detection capability. Photoneutron plants for beryllium recovery have been operated in Russia since 1966[21]. The sensitivity of the method has been increased by the use of pulsed-electron accelerators that have enabled the sorting of lead, mercury, uranium, tungsten, lithium, iron, and rare earth minerals.

Table 7 indicates radiometric sensing systems in use.

**Table 7**
**Sensing Systems Based on Radioactivity**

| Feed size range | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 10 to 2-in. (25.4 to 5.1-cm) | 5 | Natural | Radiometric | Special design |
| 10 to 2-in. (25.4 to 5.1-cm) | 1 | " | " | Model 6 |

*See Table 1-A; **See text.

## X-Ray

*Transparency* — The fact that X-rays will penetrate to different depths depending upon the density of the exposed object is well known. X-ray transparency may also be used to distinguish minerals of differing density. In this system, Figure 14, an X-ray beam is focused on a detection device, usually a scintillation counter. The feed to be sorted is delivered to intersect this beam. Low-density pieces will transmit the X-rays while high-density pieces will interrupt them. An electrical signal may thus be derived.

The slurry system[20] employs a variation of the X-ray transparency method for diamond sensing. It is required 1) that the presentation cell be full at all times to avoid false signals from air voids, 2) that the feed be sized to provide a range in which the largest particle is approximately twice the diameter of the smallest, and 3) that the depth of slurry be roughly twice the diameter of the largest particle to ensure sufficient intensity of screen fluorescence. The stream of slurry is exposed to X-rays from one side and a fluorescent screen is placed on the other. This screen is monitored by a television camera or other photosensitive detector. The high transparency of diamonds to X-rays results in luminescent streaks on the screen as they pass through the presentation cell. The intensity of these streaks is above that set for the detection device, therefore a signal is produced. The number of detections may be recorded by a counter.

*Fluorescence* — A practical application (Figure 15) of X-rays as a means of discrimination, is exemplified by diamond sensing. Feed is exposed to a beam of high-intensity X-rays in complete darkness. Focused on this irradiation area are photomultiplier tubes. Visible light emitted by the diamonds under the stimuli of X-rays is said to be[24] due to ionization of the air surrounding the diamonds because of Compton scattering. The method will detect diamonds of all types and colours, including black.

A system based on X-ray fluorescence was developed[12] in which mineral irradiation was achieved by bombarding the pieces with high-energy electrons, usually derived from radioisotopes, or with X-rays. With such systems, careful shielding is necessary to direct the X-rays to the irradiation point and to prevent scatter (health hazard). With X-rays, it is also essential to guard the tubes against accidental breakage. Because the emission of X-rays from irradiated material is immediate, sensing devices are usually focused on the same point or in the same plane as the irradiating devices.

**Figure 14.**
**X-ray transparency sensing**
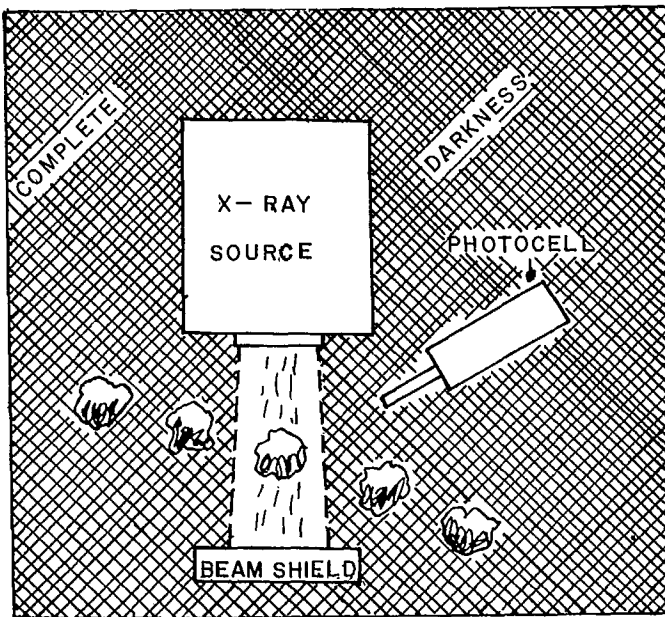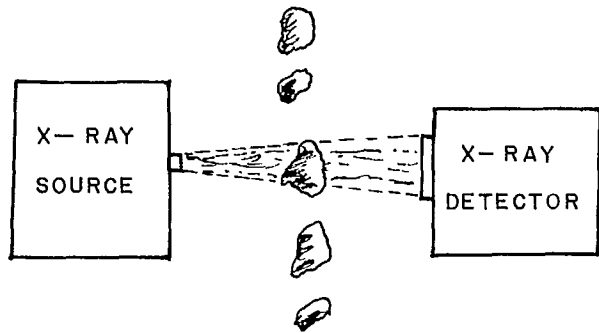


**Figure 15.**
**X-ray fluorescence sensing**

When bombardment is performed with high-energy electrons from a radioactive source, some of the electrons are scattered. Those that penetrate the piece of rock produce the characteristic X-rays, which identify the elements present, also a general background radiation spectrum. These various emissions move from the object piece in all directions. It is therefore necessary to select a portion of them for examination. Such a sensing device is illustrated in Figure 16. The collimators select a beam which is directed to the scintillometer. The magnet serves to divert stray electrons from the beam. A pulse-height analyzer may be used to identify the X-rays emitted from the sample.

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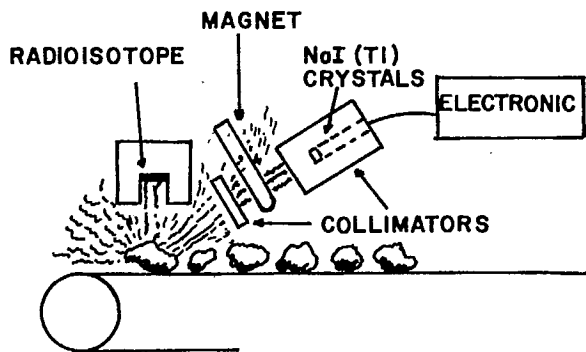
**Figure 16. X-ray fluorescence sensing**

A limiting factor in the sorting of minerals by this means is that for elements of relatively low atomic number, the characteristic X-rays that they emit after bombardment are readily absorbed by air. Elements above atomic number 36 (Table 6) can be handled satisfactorily. Certain elements below this number may be detected, but air absorption problems rapidly increase and the detection system must be placed too close to the mineral pieces for practical application.

Table 8 shows sensing systems in use based on X-rays.

**Table 8**
**Sensing Systems Based on X-Rays**

| Feed Size Range | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 0.312 to 0.031-in. (8.0 to 0.8-mm) | 3 | Fluorescence | Diamonds | Special design |
| 1.25 to 0.031-in. (32.0 to 0.8-mm) | 10 | " | " | Slurry system |
| 0.375-in. to 14 mesh (9.5 to 1.2-mm) | 2 | " | " | Model XR 21 |
| 1.25-in. to 7 mesh (32.0 to 2.8-mm) | 2 | " | " | Model XR 11 |
| 7 to 1-in. (17.8 to 2.5-cm) | 8 | Transparency | Coal | Watson X-Septa |
| 8 to 2-in. (20.3 to 5.1-cm) | 5 | Fluorescence | Heavy elements | Special design |

*See Table 1-A; **See text.

*Optical*

This properly embraces all areas for which the sensed property is light. For practical purposes, this extends from the ultraviolet, through the visible, and into the infrared, although luminescence may be induced in many minerals by irradiation.

Fluorescence, transparency, reflectance, or any other light-influencing property specific to one component of a feed may be employed. The X-ray inducement of diamonds to fluoresce with visible light production may be considered as transitional between the radioactive and the optical areas of sensing. A number of other minerals, e.g., fluorite, sphalerite, scheelite, kunzite, will also fluoresce under X-radiation. Owing to the cost of X-ray production, however, the method is currently restricted to diamonds.

*Fluorescence* — Luminescence phenomena result from the spontaneous emission of photons, i.e., the drop from one energy level to the next lower in an excited molecule. It is therefore necessary to first excite the molecules of any given material through energy input, e.g., heating and irradiation. The material so excited may immediately produce the reverse action. Decay rates are finite and may be measured[24]. The term fluorescence is usually applied to the very short decay rates, while the term phosphorescence is usually applied to rates longer than 1/10 second or visible to the human eye. There is an optimum wavelength of exciting radiation for most materials.

Although luminescence phenomena may be observed in a large number of substances its association with minerals is limited. Fluorescent minerals generally are crystalline but contain some impurity. Exceptions are certain uranium compounds and scheelite, which fluoresce as pure materials. Because of the impurity factor, a mineral from one source may fluoresce well but the same mineral from another source not at all. Thus tests for possible fluorescence should be made on all prospects for this type of scanning.

The costs of gamma or X-ray production practically preclude either one as a general method of excitation. Fluorescence sensing of visible light excitation presents practical difficulties. Infrared excitation would cause emissions of even longer wavelength, which would be very difficult to detect. Therefore ultraviolet excitation represents the probable productive area. Ultraviolet in the wavelengths adjacent to visible light is called "near" and that ranging closer to X-rays is called "far."

The chief mineral prospects for fluorescence sensing are given in Table 9.
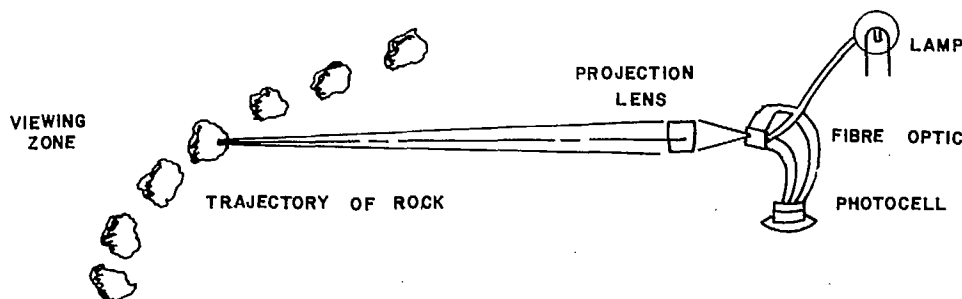


**Figure 17. Translucency sensing**

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Table 9
Fluorescent Mineral Prospects

| Mineral | Composition | Ultraviolet range | | Probable Colour of Fluorescence |
| | | Near 4-300 m$\mu$ | Far 3-200 m$\mu$ | |
| --- | --- | --- | --- | --- |
| Scheelite | $CaWO_4$ | | x | Light blue |
| Fluorite | $CaF_2$ | x | | Violet to green |
| Spodumene | | | | |
|   Kunzite | $LiAl(SiO_3)_2$ | x | | Reddish yellow |
|   Hiddenite | $LiAl(SiO_3)_2$ | x | | Purple |
| Calcite | $CaCO_3$ | x | | Red |
| Willemite | $Zn_2SiO_4$ | | x | Green |
| Quartz | | | | |
|   Chalcedony | $SiO_2$ | x | | Yellow-green |
|   Opal | '' | x | | '' |
|   Agate | '' | x | | '' |
| Spinel | $MgAl_2O_4Cr$ | x | | Red |
| Kyanite | | | | |
|   Disthene | $Al_2SiO_5Cr$ | x | | Red |
| Corundum | | | | |
|   Sapphire | $Al_2O_3Ti$ | x | | Orange-red |
|   Ruby | $Al_2O_3Cr$ | x | | Red |
| Beryl | | | | |
|   Emerald | $Be_3Al_2(SiO_3)_6Cr$ | x | | Red |
| Autunite | $Ca(UO_2)_2P_2O_8.8H_2O$ | x | | Greenish yellow |
| Torbernite | $Cu(UO_2)_2P_2O_8.12H_2O$ | x | | '' |
| Diamond | C | x | | |

The arrangements for fluorescence scanning would be similar to those for diamonds (Figure 15), substituting ultraviolet for X-rays and reducing the amount of shielding.

*Photometric* — Numerous sensing devices have been based on the narrow, visible-light band. This area of sensing also accounts for most of the equipment in use. It deals essentially with light transmitted through mineral particles or with light reflected from them. Discrimination on the basis of colour, i.e., pigmentation, would be an obvious approach. Unfortunately, colour quality is highly variable in mineral pieces, so a satisfactory means of sensing colour accurately has yet to be developed. However, by using filters, specific wavelength bands may be isolated. A minimum reflectance difference of 5 per cent between such bands will allow an effective separation.

Light reflecting from mineral surfaces may vary in brightness or intensity, regardless of colour or shade. To the eye a mineral may present shades of a specific colour, or have a distinct lustre. Shades may appear altered by light incident on the surface. There may be specular reflections such as highlights and glitter.

The device employed in all optical sensing is the phototube which is sensitive to changes in the intensity of light falling upon its cathode. The phototube does not discriminate transmitted light, direct or specular reflection, lustre, colour, or shade. To make practical use of these elements with phototube detection it is necessary to employ modifying methods. Reflectance is commonly measured with diffuse lighting to avoid specular effects. Polarizing techniques may also be used for this purpose, and to control the light in transparency sorting. In some cases, lustre may be used for differentiation. As indicated above, filters may be employed, usually in association with diffuse illumination.

*Transparency* — A simple and positive discrimination method may be applied to the relatively few minerals that are transparent or translucent. This is essentially the same action as automatic door opening. A beam of light falling on a phototube is broken, in one case by the human body and in the other by an opaque mineral. In either case, a signal is produced. It may be found advantageous to employ polarizing techniques with translucent minerals to take advantage of the scattering, or depolarizing, of the light as it traverses the mineral. Both single-line and single-layer presentation systems may be scanned by transparency sensing. In the latter case diffuse illumination is produced with a ground glass screen. A long slit, to cover the full width, is placed on the opposite side of the feed stream. This is viewed by a phototube through a high-speed, slotted, rotating disc with a series of magnetic slugs arranged around its periphery. These slugs produce pulses that serve to locate an unwanted piece in the stream when detected by the phototube.

A detection system based on the light scattering effect of translucent material has been developed[23]. A small section of each subject piece is illuminated, preferably as a small band. The image of this band is prevented from reflecting directly into a photocell so that only scattered light, originating in translucent material, is detected by the cell. Output of the cell thus becomes a measure of translucency, and pulse peaks above a preset level may be used to accept or reject the subject pieces. By employing fibre optics, compact detector heads have been designed to provide both illumination and light collection via a single unit. Several units may be used to scan a single piece of feed from all sides. *See* Figure 17.

*Reflectance* — Reflectance sensing is based upon comparative differences in reflection from mineral surfaces. Either the general reflectance from a mineral surface may be scanned or the amount of a specific reflectance may be determined.

*General-Reflectance Sensing* — This method is generally applied if maximum resolution and sensitivity are not required. This is the case with smaller sizes of feed, i.e., mostly liberated. A restricted viewing field for the phototube is provided. A background is placed in this viewing field from which the area illumination is reflected and which establishes a constant electrical output from the phototube. The background is selected to provide a reflectance similar in intensity to that of the major constituent of the feed. The feed pieces are then interposed in rapid succession between the background and the phototube in line with the field of view. Those with similar reflectance to the background do not change the output of the

phototube. Those which reflect with more or less intensity than the background cause a change in the electrical output of the phototube. Filters may be used in this method to narrow the wavelength range of the light being examined by the phototube.

A convenient viewing restriction is a small rectangle, or slit. A suitable arrangement of the elements involved is given in Figure 18. The objective lens serves to focus light reflected from the background and from the mineral onto the slit. The cathode lens provides a steady beam of light at the cathode to ensure a correct reading. It will be noted that, with the slit form of viewing, the phototube observes mineral piece and background in roughly equal proportion.

Variations of this scanning method are incorporated with presentation and separation systems into a variety of machine designs. In most, presentation to provide free fall through the scanning point is used. This allows each piece to be viewed by integrated scanners set at various angles so that as much as possible of the total area of the piece is viewed.

An illustration of such a system is provided in Figure 19. Similar illuminating lamps produce bright, uniform lighting throughout the all-white scanning chamber. Hexagonal form and lamp shielding ensure that this lighting is diffuse. Viewing with three separate but integrated sensing systems focused on a scanning point allows up to 75 per cent of the surface of each piece to be inspected. Feed passes through the chamber in free fall.

An interesting variation incorporates construction of the viewing chamber with lucite. Lights at the ends of the lucite panels cause the entire chamber to become illuminated because the light follows the contours of the lucite. The lucite also serves as a background in this system.

Viewing from two sides is featured in some devices. A novelty is a hinged-angle background with one arm black and one white. By adjusting in relation to the phototube viewing aspect, varying combinations of black and white are observed.

*Specific-Reflectance Sensing* — This method, sometimes referred to as spot scanning, generally applies when a high degree of resolution and sensitivity are required. This is more often the case with larger sizes of feed where liberation is not complete and the pieces must be assessed according to the ratio of desirable to undesirable mineral. The action here is to examine specific areas of mineral surface by greatly restricting the viewing field of the phototube, i.e., to about 0.125-sq inch (3.2-sq mm). By moving this small viewing field rapidly across the viewed surface in successive traverses, the entire exposed surface may be inspected as each piece passes the scanning point. If the feed is composed of relatively homogeneous, or liberated, pieces the net result is similar to that of general-reflectance sensing. More often the larger feed pieces are composed of two or more different minerals. In this case, it is necessary to estimate the content of wanted and unwanted material and to retain only those pieces that have predetermined "wanted" contents. To do this the phototube standardizing background is selected to be brighter than the brightest feed pieces. Scanning the viewed pieces thus always produces a series of signals which can be used to delineate the total area of the viewed face. At the same time,

areas that are darker than the general surface being scanned produce a greater reduction in output from the phototube. These superimposed signals can be used to delineate the total dark area exposed. Filters can be used to narrow the wavelength range if necessary.

The device generally used for specific-reflectance scanning is a disc with equally spaced small holes close to the periphery. This is placed so that the small holes intersect the field of view of the phototube. When the disc is rotated at high speed, a series of traverses across the face of the falling subject piece is obtained. The system for general-reflectance, as illustrated in Figure 18, may be converted to the system for specific-reflectance by inserting such a disc. This is depicted in Figure 20.



SIDE VIEW

PHOTOTUBE VIEW
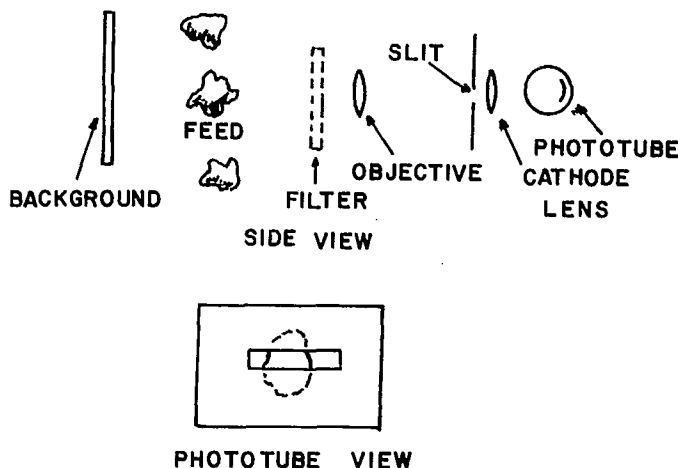
Figure 18. General reflectance sensing



PLAN

SECTION A-A
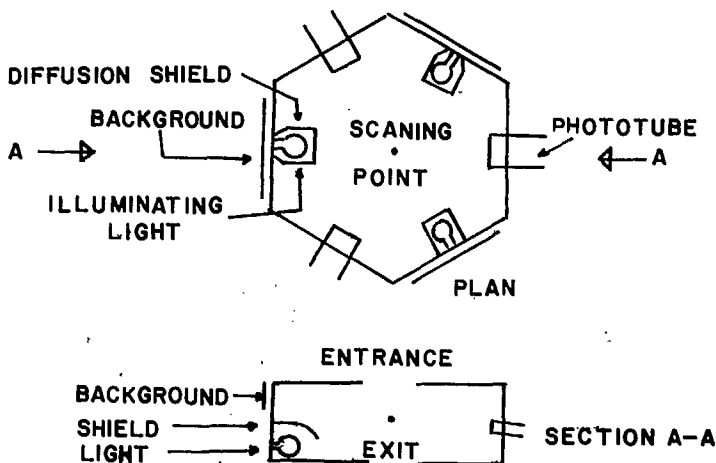
Figure 19. Reflectance sensing arrangement

23

BACKGROUND

FILTER

CATHODE
LENS

SLIT

PHOTOTUBE

OBJECTIVE

SCANNING
DISC

FEED

SIDE VIEW

PHOTOTUBE VIEW
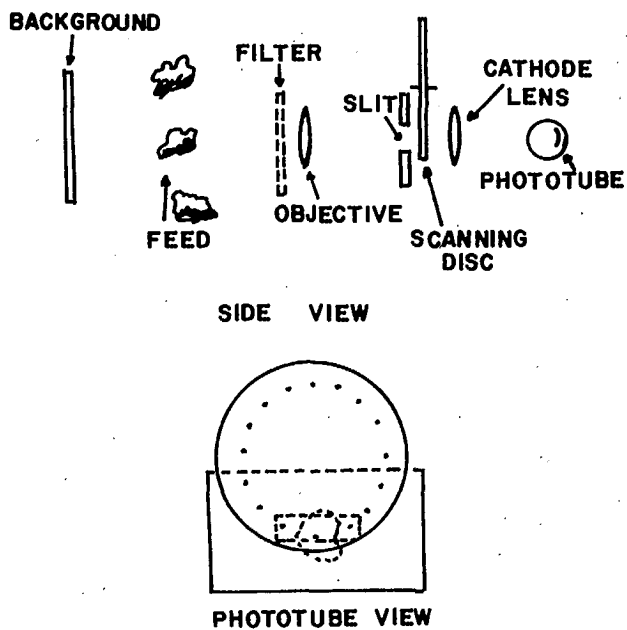
Figure 20. Specific reflectance sensing

C

D

B

A

A Conveyor

B Light

C Curtain

D Photocell
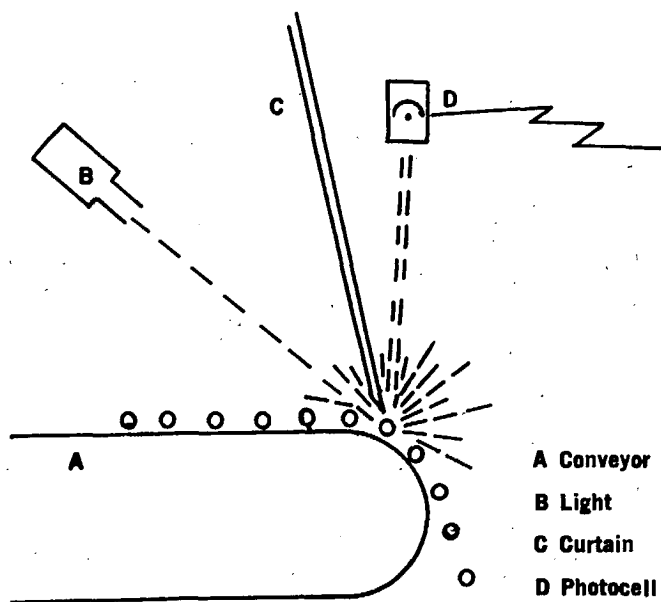
Figure 21. Sensing by depolarization

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Variations are incorporated with presentation and separation systems to produce the different machine designs. If free fall presentation is used, the method of integrating two or three sensors to view from different angles may be employed. In other cases, only one surface of the feed piece is viewed.

The scanning system depicted in Figure 19 has been employed on a larger scale, with specific-reflectance sensing, to accommodate larger feed. Single-layer presentation may be scanned with a method similar to that described for transparency sorting.

Some photometric sorting systems currently in use are given in Table 10.

*Novel Arrangements* — The depolarizing effect derived from light scatter as it passes through minerals was developed[9] as a means of detecting diamonds. Polarized light is focused on the particles of gravel at the point where they pass under a curtain. On the opposite side of the curtain a phototube is also focused on this point through a crossed polarizer. A diamond passing the scanning point scatters enough light beyond the curtain to be detected. Figure 21 illustrates the method.

The fact that many minerals produce specular reflections that are more intense than their general, or diffuse, reflections was used[6] in an interesting but somewhat complex sensing system (Figure 22). The general light reflected from a piece of feed is focused by the peripheral part of a convex lens at the axis of the optical system. The central part of this lens has been replaced by a segment of prismatic convex lens. This diverts the specular reflectance of the feed piece to focus at a point in
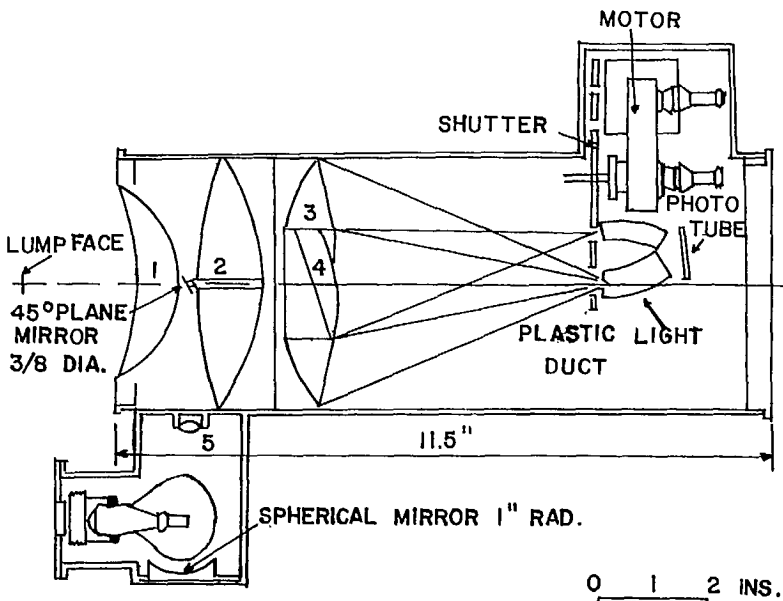


Figure 22. Specular reflectance sensing

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the same plane as the diffuse reflection but about 1-inch (2.5-cm) off the optical axis. At each focus point the light is picked up by the end of a lucite rod curved so that the light from both exits onto a single phototube. By inserting a rotating disc with staggered slots just before the focus points, the phototube receives diffuse and specular reflections in quick succession. If specular reflection is registered, a signal is produced by the phototube.

The fact that light tends to be more polarized on reflection from a smooth surface than from a rough one has been used[7] in a sensing system. Light is reflected from the mineral surface through a rotating polarized disc which alternates the crossed and uncrossed positions. These variations are picked up by a phototube which signals the more polarized reflection from the smoother pieces. The method is illustrated by Figure 23.

**Figure 23**

**Polarized reflectance sensing**
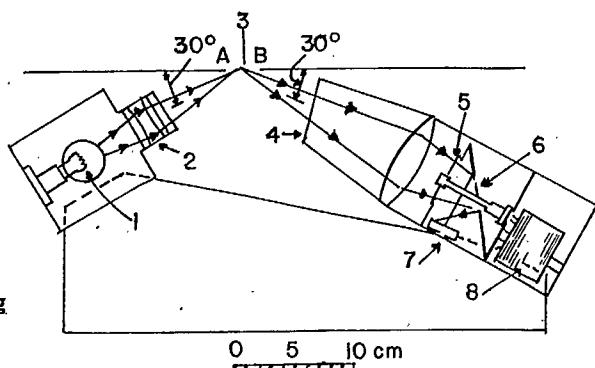
FIG. 2 — Optical system.

1. Light.   2 Condenser lenses.   3. Viewing   aperture.
4. Perspex window. 5  Poloroid disk rotating on motor shaft.
6. Metal mirror.  7. Photo·electric  cell 8. Motor.

**Table 10**
**Photometric Systems for Sensing**

| Size of Feed | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 4 to 10 mesh (4.8 to 1.7-mm) | 12 | General Reflectance | General | Model G3800R |
| 0.75-in. to 7 mesh (19.0 to 2.8-mm) | 2 | " | " | Model 962M |
| 0.75 to 0.25-in. (19.0 to 6.4-mm) | 2 | " | " | Model 621M |
| 0.625 to 0.5-in. (16.0 to 12.7-mm) | 2 | " | Salt | Model G512 |
| 2 to 0.75-in. (5.1 to 1.9-cm) | 2 | Specific Reflectance | General | Model 711M |
| 6 to 2-in. (15.2 to 5.1-cm) | 2 | " | " | Model 811M |
| 12 to 4-in. (30.5 to 10.2-cm) | 4 | " | Limestone | Special design |

*See Table 1-A; **See text.

An interesting new application has been introduced[25] for maintaining an accurate cut point in wet tabling operations. Two photocells, together with light sources, are shielded by a hood to prevent physical damage and also to prevent excessive ambient light from intruding on the target area. The photocells are selected for spectral response in the wavelength range represented by light reflected from the material being scanned. The cells are spaced to observe either side of the line of demarcation between two types of mineral being separated on the table deck. The hood is suspended about three inches above the target area. If the line of demarcation shifts slightly in either direction, a characteristic of table operation, the shift is detected and the cutter for separating the products is automatically moved to the correct position.

A novel extension of the specific-reflectance sensing system has been achieved. This is done by a series of mirrors around the periphery of a rotating drum. A fine laser "pencil" reflects from a moving mirror to sweep across the moving pieces of feed. A second mirror picks up the reflection from the area illuminated by the laser beam and routes it onto a phototube. The laser provides a high-intensity source of polarized light without either generating excess heat or the energy loss developed by polarizing filters. The system gives area of surface scanned, general reflectance, specific reflectance, and location of the scanned piece in a feed stream.

*Infrared* — Broadly, all wavelengths longer than the visible are infrared. In practice the range extends from the red, 0.7 $\mu$m, to around 500 $\mu$m. Infrared optics present some difficulties because of the wide range covered, but various materials have been developed for use as filters and as detectors. Scanning devices, highly sensitive to minute heat differences, are available. Minerals absorb heat at different rates and are often sensitive to narrow wavelength ranges. Specific wavelengths of infrared are altered slightly on reflection from different surfaces, the amount of alteration varying with the surface. Infrared aerial photography employs this principle. Other infrared photographic techniques are well developed.

This knowledge appears to offer good prospects for the evolvement of infrared sensing devices applicable to mineral sorting. However, there have been very few such applications. An example is provided[13] by a development for the detection of asbestos in rock. The asbestos has lower thermal conductivity and higher surface area than the enclosing rock. Therefore, while exposed to a flame, the asbestos heats more rapidly than the rock. Pieces of feed containing asbestos may be identified by scanners that measure the infrared radiation emitted. For this purpose, lead sulphide detectors are used and the pieces are viewed from two sides with integrated scanning.

### Radio Frequency

An unusual sensing system, described by the manufacturer as radio-frequency permeability detection, has been applied to the sorting of native copper ores. Such a system should have application in other situations involving material that is dense to radio waves. Sensing is accomplished[14] by means of a coil which forms part of

an oscillator. This is tuned to a second, or reference oscillator, so that a low-frequency beat is produced. When metal enters the field of the coil, there is an alteration in the frequency of its oscillator. The beat frequency is thereby altered and a signal is produced.

*Conductivity*

Many mineral and rock fragments are capable of conducting electricity. Electrical conductivity will vary widely depending upon composition, e.g., iron is 10,000 times as conductive as chalcopyrite which is 100 times as conductive as hematite. By measuring the flow of current through fragments, these differences may be determined. Those allowing current flow above a predetermined level will produce a signal.

Because mineral fragments vary widely in shape, grain size, and mineral distribution, pieces of similar general composition may vary considerably in conductivity. Therefore conductance sensing is usually not capable of detection to a precise cut-off. The least conductive pieces to be accepted should be at least 4 times as conductive as the most conductive pieces to be rejected. Those falling between may report in either group. If a relatively small range of difference in conductivity exists in a feed, it cannot usually be separated by this means. Nor is the method completely effective for removing a small content of highly conductive pieces from a large bulk of feed.

The sensing system employed, Figure 24, consists simply of measuring the current flow through feed pieces as they pass between a grounded plate and suspended electrodes.

*Low-Voltage* — Low-voltage sorting is used in certain situations involving damp feed. Contact between electrodes and feed pieces is necessary with low
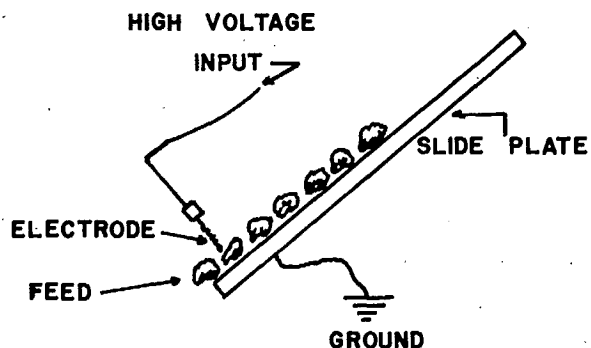


Figure 24. Conductance sensing

voltages, hence the electrodes must be designed with care. The technique is best applied to the separation of two homogeneous materials, e.g., hematite and shale. It may also be used to detect porous material, e.g., in concrete aggregate. In this case, the feed is well wetted and then drained. Porous pieces retain more water and thus have lower electrical resistances than the solid pieces.

*High-Voltage* — High-voltage can be used only if the feed is dry. Potentials between 5 and 20 kV are required, so transformers or induction coils must be located close to the electrodes. High-voltage sensing becomes operative when there is an ionizing discharge between the electrode and the subject piece of feed, i.e., when arcing begins. Arcing presents little resistance to the current flow between the electrode and the subject piece. Voltages above minimum may be applied as required and the system can be used differentially. In this case, a cut of more highly conductive pieces may be removed at one voltage and a second cut of less conductive pieces may be removed at a higher voltage.

## ELECTRONICS

Modern developments in electronics have provided the technical ability to create sorting devices. It is not necessary for sorting purposes to know the specifics of electronics but only how they apply. Sensing provides the eyes, and electronic systems provide the brains for selective sorting machines.

### Sensing

An indication of the electronic devices applied to sensing was given in Table 5. Of these, only the phototube requires brief elaboration. Many varieties of phototube are available[15]. Those generally applied in sorting are, a) the photodiode, when low resolution applies, and b) the photomultiplier, when high resolution is required. Low resolution indicates strong contrast (black and white). High resolution involves slight differences, as in shades of the same colour.

In addition, a number of tubes with either a narrow or a broad range capability may be used, e.g., the lead sulphide infrared detector.

### Decision

Decision making requires the necessary circuitry to amplify and act upon the signals received from the sensing system.

After producing an electrical signal, the sensing device has completed its work on a particular rock fragment. The decision-making electronic system picks up the signal and processes it. If the decision is to "reject," the system signals the separation device to that effect.

The arrangement and compass of the decision system will increase with the number of decisions required, i.e., complexity increases with the number of pieces simultaneously handled and with the number of factors that must be integrated. Relatively complex situations will employ computer-type circuitry. In all cases, the decision process will provide accurate millisecond delay times to allow the fragment to travel from the sensing point to the separation point.

In the case of electrical resistance (conductance sorting), the circuitry usually measures current flow.

A comparatively simple decision system, as for general-reflectance sensing, would amplify the phototube signal, run it through a phase inverter, a gate system, and a pulse shaping and extension system. The processed signal would then be given a millisecond delay corresponding to the time for a particle to travel from "sense" to "separate." Finally, the signal would be amplified to operate the ejector solenoid. A graphic illustration of this action is given in Figure 25. The output of the phototube will trip the separation system whenever its amplitude exceeds a voltage level preselected by the equipment operator. The operator can reverse the action, from removing lighter than average pieces to removing darker than average pieces, if desired.

With the specific-reflectance sensing method the decision process is considerably more complex. The rock fragments are viewed by a rapidly executed series of traverses as indicated in Figure 26. The electronic action is illustrated graphically in Figure 27. Numbers on the scan waveform correspond to the traverses in Figure 26. Because the background governing the phototube emission is lighter than the lightest rock colour, both size of fragment and discolouration thereon may be determined. Spot scanning is accomplished by viewing through a series of small holes, so there will be a scan period (a-a on the scan waveform), followed by a blank period (b-b) because of the space between holes on the scanning disc; a-a represents 100 per cent reflectance, and b-b represents zero reflectance. At traverse 3, the rock fragment appears and this causes a change in reflectivity during part of the traverse. This is shown as c-c on the scan waveform. At traverse 5 the blemish on the rock fragment is also picked out to produce a second, superimposed change in reflectivity. This is shown as d-d on the scan waveform.

The complex waveform thus produced is amplified and fed to a discriminator unit which a) generates a gate waveform that encompasses the significant scan periods, b) produces a size pulse that defines the width of the fragment, and c) produces a blemish pulse (when reflected light becomes lower than a preset, or discrimination, level) that defines the blemish width.

Both pulses pass into a comparator unit. By applying a constant charging rate — that for the blemish pulse being preselected — individual pulse trains are caused to build-up voltages in storage capacitors. Thus, for each piece scanned, a maximum voltage for size and a maximum voltage for blemish are built up. When blemish-voltage exceeds size voltage, a signal to the separation device causes removal of that piece. It is therefore possible with this system to preset a ratio of blemish area to surface area which will cause separation regardless of the actual size of rock fragment. This action can be reversed to cause removal of material lighter than the background, should this be more appropriate.

Decision making in radiometric sorting is similar. The control centre is, in essence, a simple computer which integrates fragment-size data with analysis data

(obtained from the scintillation counter) and compares the result with a predetermined cut-off level. Fragments, registering above the cut-off, cause the signal to be relayed to the separation system.

In even more sophisticated situations, e.g., single-layer presentation with continuous scanning, the signal is processed by computer circuits which have been programmed to deal with the particular feed being sorted. The size of the particle is determined, the ratio of its differing surface tones is assessed, and its position in the stream is fixed. For each particle, this information is stored in a different analyzing module, integrated, and compared to the programmed standards. For pieces which meet these standards, the signal is relayed to a particular unit of the separation system so that, after a correct time interval, the piece is in the necessary position for removal from the stream of feed.

## SEPARATION

Separation is the process of accurately removing from the bulk of feed those pieces which the sensing and decision mechanisms have selected for removal.

Essential features of a separation system are speed of action, reliability, and mechanical strength. Though a wide variety of separation mechanisms have been devised and applied, those most commonly employed are fast-acting solenoid valves that release short aimed blasts of compressed air. This method allows precision of control together with long and relatively maintenance-free life. Other kinds of mechanical devices involve higher levels of inertia with consequent slower response, usually some friction, and more maintenance.

### Air Blast

Because a particle in free fall requires a comparatively small impulse to divert it from its normal path, air blast separation is usually applied in free-fall systems. Timing and direction of thrust can be accurately controlled so that the blast strikes only the selected particle despite proximity of other particles. Moreover, the air-blast system is effective for diverting large pieces as well as small. The chief requirement is to tailor the air system (valves, passages, nozzles, and pressure) to suit the size of feed being processed. Pieces of up to 150 lb (68 kg) have been diverted in systems using 90 psi (6.3 kg/cm$^2$) air through 1-inch (2.5 or 2.54-cm) valves developing maximum thrust in 5 milliseconds. Air blast valves range down to 0.06-inch (1.5-mm) bore units which open for 1 millisecond and operate at up to 700 blasts per second.

The rate of air use is dependent upon: a) feed rate, b) the proportion of feed being removed, c) the size of feed pieces being removed, and d) the density of the pieces being removed.

The number of blasts per unit time may be determined from the feed rate and the proportion to be removed. The pressure used, the size, and the number of outlets employed must be determined from the size and density of the pieces to be removed. Because small valves for small feed operate many times per second and large valves
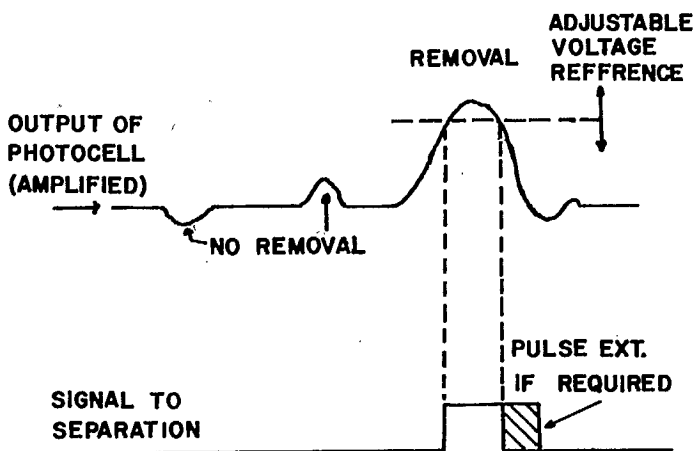
Figure 25. Simple electronic action
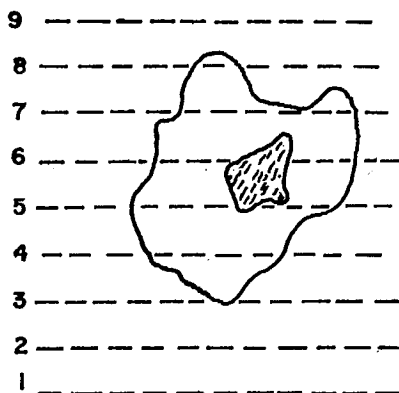


Figure 26. Scanning traverses over fragment

for large feed operate only a few times per second, air consumption tends to increase with smaller sizes of feed. Careful timing and duration of air blast aids in air economy. Where possible, the minor constituent should be removed to minimize the required number of blasts per unit of feed. Though the number of blasts per ton of material removed is comparatively small for large feed, each blast requires a larger volume of air at higher pressure, e.g., 1 to 2.5 cu. ft. (0.28 to 0.71 cu m) of 80 to 90 psi (5.6 to 6.3 kg/cm²).

Differences in design of separating equipment inhibit the development of a universal formula for determining air requirements. Some machines have an air-rinse system for dedusting feed. Either a blower or vacuum is used. Typical air requirements are indicated in Table 11.

The design and mounting of air-blast separation systems vary but the principal component is usually a plunger type valve with the plunger movement controlled by a solenoid. The response time of such valves is very rapid, varying from 1 to several milliseconds depending upon the size. The air released is guided to the separation point through aimed nozzles, or slots. For small feed pieces, single jets can be used, or for large chunks, multiple converging channels can be employed.

A somewhat more elaborate system is required for the single-layer presentation method than for the single-line method. As an example, conductance sorting (see Figures 7 and 24) uses a series of slots across the bottom of the presentation slide and immediately downstream from the sensing electrodes. The distance between a line directly below the electrodes and the slots must be carefully adjusted for each feed to ensure that the piece to be removed is directly over the slot at the moment of maximum air blast. In time terms this will be approximately 6 milliseconds, the
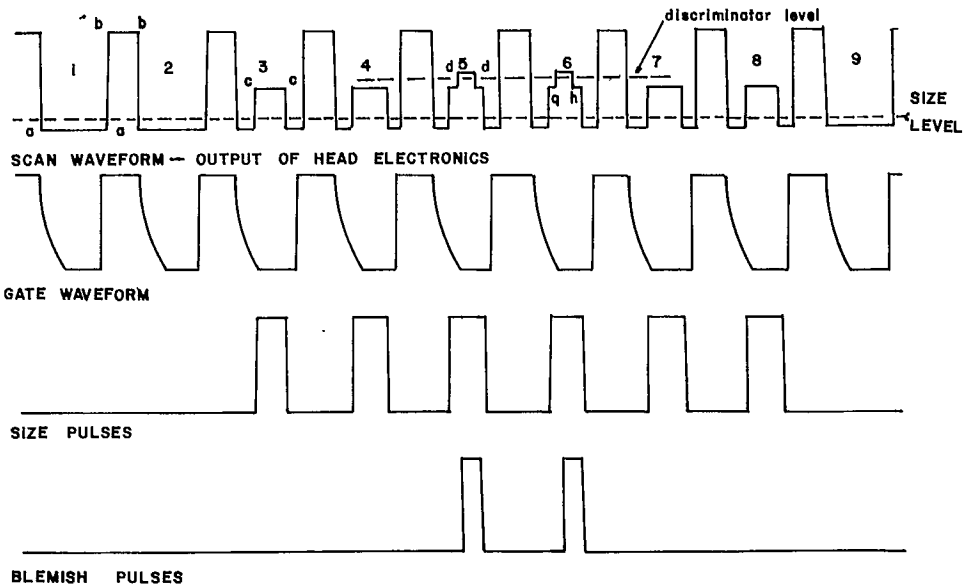


**Figure 27. Involved electronic action**

## Table 11
## Average Air Requirements

| Model | Source* | Feed size | Air cfm (m³) | Pressure psi (kg/cm²) | Air rinse cfm (in. WG)m³ |
|---|---|---|---|---|---|
| GA 2x2 | 4 | 0.75 to 0.25-in. (19.0 to 6.4-mm) | ±3 (0.85) | 80 (5.6) | |
| 10 | 1 | 2 to 0.75-in. (5.1 to 1.9-cm) | 700 to 1200 (200 to 430) | 90 (6.3) | |
| 10 | 1 | 5 to 2-in. (12.7 to 5.1-cm) | 300 to 900 (85 to 250) | 90 (6.3) | |
| 10 | 1 | 10 to 5-in. (25.4 to 12.7-cm) | 200 to 500 (57 to 140) | 90 (6.3) | |
| 962M | 2 | 0.75-in. to 7 mesh (19.0 to 2.8-mm) | ±10 (2.8) | 40 (3.0) | |
| 621M | 2 | 0.75 to 0.25-in. (19.0 to 6.4-mm) | 5 to 15 (1.4 to 4.2) | 20 to 40 (1.5 to 3.0) | 300 (4) 85 |
| 711M | 2 | 2 to 0.75-in. (5.1 to 1.9-cm) | 50 to 100 (14 to 28) | 80 (5.6) | 1000 (6) 280 |
| 811M | 2 | 6 to 2-in. (15.2 to 5.1-cm) | 300 to 400 (85 to 110) | 80 (5.6) | |
| XR112B | 2 | 1.25-in. to 7 mesh (32.0 to 3.0-mm) | ±20 (5.7) | 80 (5.6) | 1500 (7) 425 |
| XR21 | 2 | 0.375-in. to 14 mesh (9.5 to 1.2-mm) | ±10 (2.8) | 80 (5.6) | |
| Special | 9 | 7 to 1-in. (17.8 to 2.5-cm) | ±100 (28) | 80 to 130 (6.5 to 9.2) | |

*See Table 1-A.

time for maximum blast to develop after start of signal. Electrodes are placed in relation to slots so that, if the piece to be removed from the stream is directly over the slot, only that slot fires. If the piece overlaps two slots, then both fire (*see* Figure 28).

Each blast unit is made up of two separate components, a pilot valve and a main valve. Each requires a separate air supply, that for the pilot valve being above 90 psi (6.3 kg/cm²) and that for the main valve being under 85 psi (5.9 kg/cm²). A differential of 5 to 10 psi (0.35 to 0.7 kg/cm²) must be maintained to assure positive functioning.

If the sensing and decision systems indicate a piece of feed for removal, the signal is relayed to a solenoid controlling the correct valve for that piece. The solenoid immediately retracts a spring loaded plunger which shuts off the pilot air supply and relieves pilot valve pressure by venting. The pilot air, by virtue of its pressure, higher by 5 psi (0.35 kg/cm²), has been holding the main valve plunger closed. On the release of pilot air pressure, the main air supply immediately snaps the main valve plunger open and vents the main air blast through the slot.

The duration of the air blast depends on how long the current is passing through the rock piece at above the recognition level plus a 5-millisecond extension.

ELECTRODES

ELECTRODES

AIR BLAST VALVE

AIR SLOTS

SIDE VIEW

FRONT VIEW

DIVIDER
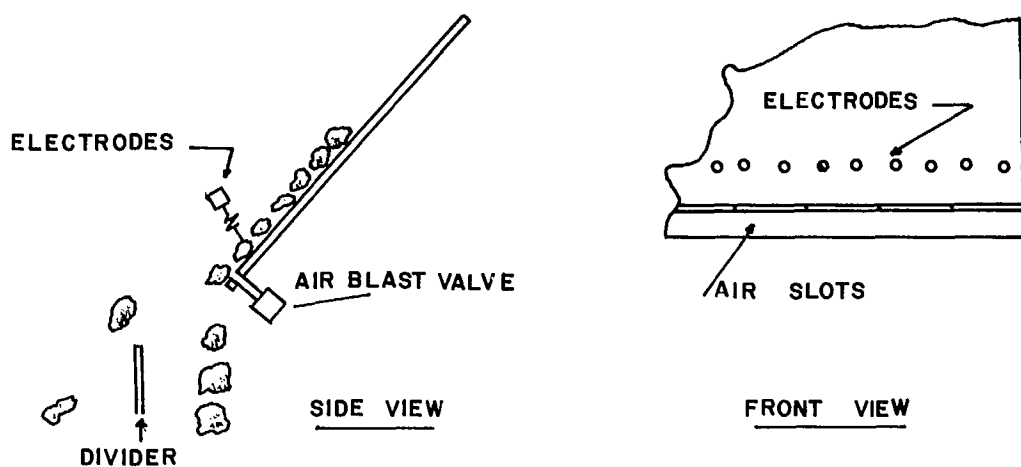
Figure 28. Multiple air-blast system
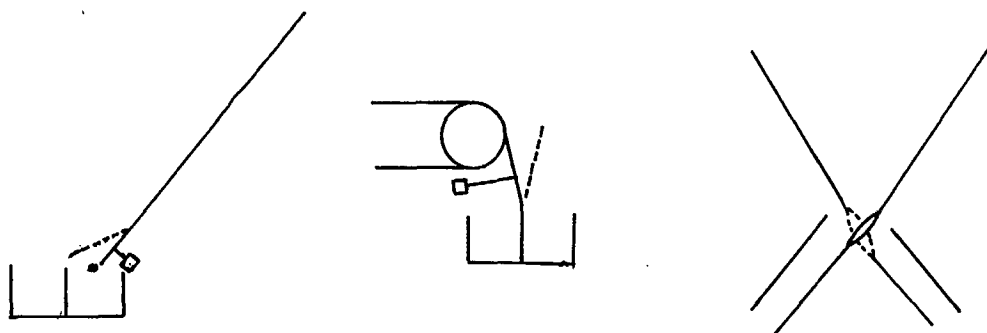


Figure 29. Gate system

As indicated earlier, it requires 5 to 6 milliseconds to develop a maximum blast with this system during which time the rock moves from sensing point to separation point. The signal has stopped before the rock reaches the separation point and the 5-millisecond extension of the blast ensures removal.

After the energizing current stops, the solenoid immediately releases the pilot plunger, and the pilot valve is pressurized. The higher pilot pressure plus the spring loading rapidly forces the main valve plunger to a closed position. This sequence seldom requires more than 10 milliseconds.

## Other Separation Methods

Ingenuity is abundantly apparent in the methods which have been devised for separation. This is well illustrated by the fact that equipment was developed to

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divert lightweight material by subjecting the selected pieces to a corona discharge and subsequently removing the charged particles by electrostatic attraction. A device has been patented[16] for using a water jet to divert selected pieces.

A number of developments use the mechanical gate system. This is usually part of a chute, or slide, which may be moved to alter the normal course of a rock fragment. It may, however, simply be a piece of hinged plate which is moved from side to side to direct pieces in free fall into either of two paths. Some gate systems are illustrated in Figure 29.

Pushers or rams are also used. In the presentation system illustrated by Figure 10, pieces selected for removal are diverted into the lower channel by a flat pusher which forms part of the chute wall. With the sectionalized conveyor shown in Figure 8, each section is provided with a pusher. Between the upper and return portions of the conveyor is a track which starts at the sensing point and curves to the opposite side of the conveyor. On signal, a cam engages this track and the correct pusher is diverted, as the conveyor moves forward, to carry the selected piece to the edge of the conveyor and over the side onto a belt. Non-diverted pieces travel to the end of the conveyor and fall onto a second belt.

An unusual method of separation for a single-layer presentation system involves a row of flat nylon "fingers" set to direct free falling rock fragments to a conveyor belt. When a piece for removal is detected, solenoids governing the correct fingers are signalled. The solenoids release restraining catches so that the fingers may be depressed by the piece striking them thus allowing that piece to fall on a parallel conveyor belt. See Figure 30.

Table 12 indicates the applications of the various separation systems.
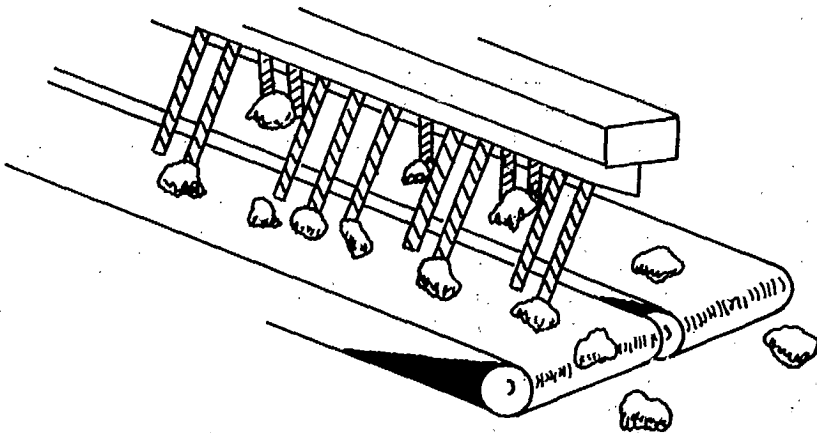


Figure 30. Finger system

**Table 12**
**Separation Systems**

| Feed size | Source* | Type** | Use | Notes |
|---|---|---|---|---|
| 4 to 10 mesh (4.8 to 1.7-mm) | 12 | Air blast | General | Model G3800R |
| 0.375-in. to 14 mesh (9.5 to 1.2-mm) | 2 | " " | Diamonds | Model XR21 |
| 0.75-in. to 7 mesh (19.0 to 2.8-mm) | 2 | " " | General | Model 962M |
| 1.25-in. to 7 mesh (32.0 to 2.8-mm) | 2 | " " | Diamonds | Model XR11 |
| 1.25-in. to 7 mesh (32.0 to 2.8-mm) | 14 | Gate | " | Special |
| 0.625 to 0.5-in. (16.0 to 12.7-mm) | 2 | Air blast | Salt | Model G512 |
| 0.75 to 0.25-in. (19.0 to 6.4-mm) | 2 | " " | General | Model 621M |
| 5 to 0.5-in. (12.7 to 1.3-cm) | 1 | " " | " | Model 12 |
| 2 to 0.75-in. (5.1 to 1.9-cm) | 2 | " " | " | Model 711M |
| 4 to 0.75-in. (10.2 to 1.9-cm) | 13 | Gate | Non-metallics | Special |
| 4 to 0.75-in. (10.2 to 1.9-cm) | 17 | Pusher | Coal | Special. |
| 7 to 0.75-in. (17.9 to 1.9-cm) | 9 | Air blast | General | Special |
| 10 to 0.75-in. (25.4 to 1.9-cm) | 1 | " " | " | Model 10 |
| 6 to 2-in. (15.2 to 5.1-cm) | 2 | " " | " | Model 811M |
| 7 to 1-in. (17.8 to 2.5-cm) | 8 | Fingers | Coal | X-Septa |
| 4 to 1.25-in. (10.2 to 3.2-cm) | 1 | Air blast | General | Model 13 |
| 8 to 2-in. (20.3 to 5.1-cm) | 5 | Gate | Heavy elements | Special |
| 10 to 2-in. (25.4 to 5.1-cm) | 1 | Air blast | Uranium ores | Model 6 |
| 10 to 2-in. (25.4 to 5.1-cm) | 5 | Gate | " | Special |
| 12 to 4-in. (30.5 to 10.2-cm) | 4 | Pusher | Limestone | Special |

*See Table 1-A; **See text.

## MISCELLANEOUS

### Capacity

Sorting systems deal with mineral pieces on an individual basis, therefore capacity per machine unit depends upon how many pieces can be handled per unit of time. Table 2 shows a relationship between size of piece and number of pieces per ton. It is apparent that capacity depends upon particle size. Specific gravity of the feed also affects capacity as, to a lesser extent, does particle shape.

Single-line presentation systems inherently have lower capacity than single-layer. However, single-line equipment provides adequate capacity, particularly on coarse feed sizes, for most purposes. Approximate capacity for current equipment on different materials is shown in Tables 13-A, -B, and -C.

**Table 13-A**
**Single-Layer Presentation — Ore Sorters Equipment**

| Model | Type | Feed | Material | Short Tph |
|-------|------|------|----------|-----------|
| 6 | Radiometric | 4 to 2-in. (10.2 to 5.1-cm) | Uranium ore | 15 to 30 |
| 6 | " | 10 to 4-in. (25.4 to 10.8-cm) | " " | 35 to 55 |
| 10 | Conductance | 2 to 0.75-in. (5.1 to 1.9-cm) | General | 20 to 75 |
| 10 | " | 5 to 2-in. (12.7 to 5.1-cm) | " | 75 to 200 |
| 10 | " | 10 to 5-in. (25.4 to 12.7-cm) | " | 200 to 350 |
| 12 | Photometric | 1 to 0.5-in. (2.5 to 1.3-cm) | " | 15 to 45 |
| 12 | " | 3 to 1-in. (7.6 to 2.5-cm) | " | 30 to 140 |
| 12 | " | 5 to 3-in. (12.7 to 7.6-cm) | " | 90 to 220 |
| 13 | " | 2 to 1.25-in. (5.1 to 3.2-cm) | " | 45 |
| 13 | " | 3 to 1.25-in. (7.5 to 3.2-cm) | " | 65 |
| 13 | " | 4 to 1.25-in. (10.2 to 3.2-cm) | " | 90 |

**Table 13-B**
**Single-Line Presentation — Sortex Equipment**

| Model | Type | Feed | Material | Short Tph |
|---|---|---|---|---|
| XR 21 | X-ray Fluoresc. | 0.375-in. to 14 mesh (9.5 to 1.2-mm) | Diamonds | 0.02 to 0.4 |
| XR 11 | " | 1.25-in. to 7 mesh (32.0 to 2.8-mm) | " | 1 to 7 |
| XR 112B | " | 0.75 to 0.5-in. (19.0 to 12.7-mm) | " | 28 |
| " | " | 1 to 0.75-in. (25.4 to 19.0-mm) | " | 34 |
| " | " | 1.25 to 1-in. · (32.0 to 25.4-mm) | " | 38 |
| 962M | Photomet. | 0.375 to 0.25-in. (9.5 to 6.4-mm) | Talc | 0.5 |
| " | " | 0.375 to 0.25-in. (9.5 to 6.4-mm) | Gypsum | 1 |
| " | " | 0.5 to 0.375-in. (12.7 to 9.5-mm) | " | 2 |
| " | " | 0.75 to 0.5-in. (19.0 to 12.7-mm) | " | 3 |
| G 512 | " | 0.625 to 0.5-in. (16.0 to 12.7-mm) | Salt | 1 |
| 621M | " | 0.75 to 0.25-in. (19.0 to 6.4-mm) | General | 0.3 to 2 |
| 711M | " | 2 to 0.75-in. (5.1 to 1.9-cm) | " | 2 to 7 |
| 811M | " | 6 to 2-in. (15.0 to 5.1-cm) | " | 10 to 50 |
| 1011 | " | 1.5 to 0.75-in. (3.8 to 1.9-cm) | Uranium ore | 3 to 5 |

**Table 13-C**
**Other Presentation Systems**

| Model | Type | Feed | Material | Short Tph |
|---|---|---|---|---|
| G-3800R | Photomet. | 10 to 14 mesh (1.7 to 1.2-mm) | General | 1 |
| Special | " | 12 to 4-in. (30.0 to 10.2-cm) | " | ± 150 |
| CSR | Infrared | ± 3-in. (7.6-cm) | Asbestos | 20-100 |

## Power Consumption

Figures quoted by manufacturers for the power requirements of their machines are given in Table 14. It should be noted that these figures are for machine operation only. If an air-rinse system is used for dedusting feed, extra power is required. In addition, the power for producing the compressed air used in air-blast separation systems must be added.

Table 14
Power Requirements

| Model | Source | Use | Feed size | Power kW |
|-------|--------|-----|-----------|----------|
| GA 2x2 | Gromax | General | 0.75 to 0.25-in. (19.0 to 6.4-mm) | 1.1 |
| 6 | Ore Sorters | Uranium ore | 10 to 2-in. (25.4 to 5.1-cm) | 4 |
| 10 | " " | General | 10 to 0.75-in. (25.4 to 1.9-cm) | 6 to 8 |
| 12, 13 | " " | " | 5 to 0.5-in. (12.7 to 1.3-cm) | 5 |
| XR 21 | Sortex | Diamonds | 0.375-in. to 14 mesh (9.5 to 1.2-mm) | 1.5 |
| XR 11 | " | " | 1.25-in. to 7 mesh (32.0 to 2.8-mm) | 3 |
| 962M | " | General | 0.75-in. to 7 mesh (19.0 to 2.8-mm) | 1.5 |
| 621M | " | " | 0.75 to 0.25-in. (19.0 to 6.4-mm) | 1.3 |
| 711M | " | " | 2 to 0.75-in. (5.1 to 1.9-cm) | 2.8 |
| 811M | " | " | 6 to 2-in. (15.0 to 5.1-cm) | 10 |

# SORTABILITY

A mineral assemblage must meet the requirements of liberation, size, and detectability in order to be sortable. In general, sorting should be applied as soon as liberation has been reached through crushing, i.e., the larger the pieces which may be discriminated the more effective the over-all sort. There is a minimum particle size below which sorting ceases to be practical; with high-value commodities, e.g., diamonds, this size may be small.

Optimum sorting size will depend upon, a) the nature of the deposit and the minerals involved, b) the sorting method employed, and c) the objectives to be satisfied by the sorting.

## MINERAL DEPOSIT CHARACTERISTICS

Sedimentary deposits containing either high-grade or impure layers may be good sorting prospects depending upon the thickness of the bands and other geological

features. During the mining and crushing of such deposits, there will be a tendency to fracture along the bedding planes with the generation of relatively homogeneous fragments and a minimum of mixed mineral fragments.

With vein deposits providing irregular or segregated mineralization the sorting prospects become variable. Material from each deposit must be treated as an individual case. It must be examined to see if there is a sufficient preponderance of the valuable constituent in enough pieces of sortable size, a sufficient lack of this constituent in enough others, and the extent of mixed, or "middling," pieces. A high proportion of middling pieces will generally make a sorting system impractical.

Deposits containing fine, evenly disseminated mineralization usually do not offer sorting prospects because the fragments resulting from mining and crushing tend to be too uniform in composition. However, if mining practice is such that undesirable waste becomes mixed with the ore, sorting may become practical. In some deposits, there is a range of mineralization from massive to finely disseminated. In such cases it may be possible to sort out a high-grade product, and leave the disseminated material for further processing.

Unconsolidated material frequently contains relatively homogeneous particles. Provided these are valuable as mineral products, they offer sorting prospects. The finer portions, such as sand, must first be removed; material above 4 mesh (4.8-mm) may be sortable.

## PREPARATION

The viability of a sorting project may depend upon the production of a sufficient proportion of the feed in sortable size, therefore the method of mining and crushing may become important. The maximum number of pieces of individual character, either rich or barren, must be produced in sortable size. This size range will have to be predetermined and arrangements made to satisfy it. Obviously the proportion of original material which ends up below sorting size is important. Excessive fines production during the mining and crushing stages increases the cost of sorter feed preparation, reduces the amount available for sorting, and diminishes the savings derivable from the sorting process. The nature of the original rock plays a considerable role in sorter feed production. With some materials, fragmentation to the best sorter size in sufficient bulk is virtually impossible. Some materials crumble, shatter, or abrade so readily that they cannot be maintained at sorting size long enough for satisfactory separation.

The smallest size of particle which may be economically sorted will vary with the circumstances but usually will be related a) to the size specification of product, b) to the capacity of the equipment, c) to the size below which it is more advantageous to apply other processing methods, and d) to the limitations of the sensing system employed. In practice the minimum size processed by sorting is usually about 0.5-inch (12.7-mm); if relatively valuable 0.25-inch (6.4-mm). Although it has been shown that separations may be made at 10 to 14 mesh (1.7 to 1.2-mm), only high-value material can be sorted at such small sizes.

## SORTING OBJECTIVES

There are three categories into which prospective sorting projects generally fall: concentration, preconcentration, and salvage. The requirements of individual cases may fall into more than one category.

### Concentration

When sorting is to produce one or more finished products the objective is concentration. This requires that the feed contain sufficient pieces, in a sortable size range, which are of a grade as high as or higher than the desired product. A number of variations apply.

The ideal situation is that which involves a direct sort into product and waste.

It may be possible to separate into two marketable products.

In some situations a marketable product may be obtainable and the remainder separated into a retreatable middling and a waste product.

It may be practical to recover a marketable product and to retreat the remainder either by additional sorting or some other process.

In certain cases the feed may be sorted into a number of fractions each of which may be sold directly, e.g., several shades of chips for exposed aggregate.

Occasionally, multiple fractions may be derived from a single feed which include more than one grade of product; also it may include a retreatable middling and/or a discard.

### Preconcentration

If sorting is to partially upgrade and produce a smaller bulk for further processing, the objective is preconcentration. This generally indicates that pieces sortable in size are mixed in composition with some tending to contain more of one mineral and others tending to contain more of another.

The ideal situation would be a direct sort into waste and an upgraded product.

It may be possible to separate into two fractions each enriched in a different mineral for separate additional processing.

In certain deposits, deleterious material may prevent or interfere with the concentration of the valuable component by an otherwise viable process. Sorting might be used to remove the unwanted material.

### Salvage

There are certain situations in which the objective of sorting is salvage.

A low-grade deposit could be made acceptable through high-capacity, low-cost sorting.

Waste dumps, or low-grade rejects from selective mining, may be sorted to recover residual mineral values.

Deposits that are uneconomic because of isolation or because of the lack of such processing necessities as water, may be preconcentrated by sorting to reduce transport costs for removal to an acceptable processing site.

A small deposit may be rendered profitable through preconcentration by sorting to a grade acceptable by a custom processer.

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# ECONOMICS

An assessment of sorting as an adjunct to the solution of a mineral recovery problem would involve 1) a decision as to whether it could materially help the situation, 2) an examination of the technical feasibility, and 3) consideration of cost-benefit factors. Information, relevant to the first, has been recorded under SORT-ABILITY and, to the second, under MECHANICS. The third deals with the over-all economics involved.

## BENEFITS

### Increased Revenue

The development of saleable new products, improved products, or increased recovery, would be revenue producing.

The value of mineral reserves would increase if sorting allowed the mining of lower grades.

If sorting helped to reduce over-all processing costs the value of mineral reserves would increase.

### Accelerated Return

If sorting replaces selective mining, the mining costs may be reduced.

If sorting is used to preconcentrate a mill feed, the mining rate may be increased in proportion.

Preconcentration by sorting may produce savings in processing costs through improved recoveries as well as increased mill capacity.

Savings may be realized in transport and other costs through upgrading by sorting, particularly if the sorting can be done underground and the discard used as backfill.

Occasionally it may be possible to sell waste for road building, concrete aggregate, or for a related use.

## COSTS

All cost factors reflect the economic climate of which they form a part. Cost information provided herein should, therefore, be taken only as a rough guide, and to provide comparison with alternative treatment methods.

In addition to capital and operating cost factors, estimates for sorting should include the value of losses to, or the cost for other processing of, rejects from the sorting process. However, if the rejects are discarded, the disposal cost should be charged to sorting.

A method for determining whether sorting is justifiable has been proposed by Gunson's Sortex Limited, as shown in Table 15.

## Table 15
### Economic justification for sorting

| | Value of feed $/ton | Value of concentrate $/ton | Value of tailings $/ton | All in sorting cost $/ton | Weight recovery in concentrate fraction | Process costs $/ton | Value of accepted tailings loss $/ton |
|---|---|---|---|---|---|---|---|
| 1) Concentrate sold<br>Tailings sold | F | C | T | S | r | — | — |
| 2) Concentrate sold<br>Tailings discarded | F | C | T | S | r | — | — |
| 3) Concentrate processed<br>Tailings discarded | — | — | T | S | r | P | W |
| 4) Concentrate processed for A<br>Tailings processed for B | — | $C_B$ | $T_A$ | S | r | $P_A$<br>$P_B$ | $W_A$<br>$W_B$ |
| 5) Concentrate processed for A + B<br>Tailings processed for B | — | — | $T_A$ | S | r | $P_A$ | $W_A$ |

SORT IF: In case (1)  $rC + T(1 - r) > F + S$

In case (2)  $rC \quad\quad > F + S$

In case (3)  $S + (T - W)(1 - r) + Pr < P$

In case (4)  $S + rP_A + r(C_B - W_B) + (1 - r)P_B + (1 - r)(T_A - W_A) < P_A + P_B$

In case (5)  $S + (1 - r)(T_A - W_A) < P_A(1 - r)$

This is a simplification in that:

(i) Transport and disposal costs are ignored (ii) Treatment cost might vary with increased metal content.

## Capital Costs

Capital costs will comprise 1) the purchase price of the necessary machines, 2) the cost of accessory equipment, e.g., to provide compressed air, dust removal, wash water, 3) the cost of additional crushing, sizing, and conveying equipment, and 4) the over-all installation costs.

Sortex employs the following method for estimating approximate capital cost of their equipment: (proposed tph) (a factor based on particle size). A 50-tph installation for 4 to 6-inch (10.2 to 15.2-cm) feed would therefore cost roughly 50 x $1,000.00; a one-tph installation for 0.5-inch (12.7-mm) feed would cost roughly 1 x $10,000. All Sortex equipment requires compressed air and some models use air dedusting. The above costs would be increased by from 50 to 200 per cent for accessory items and installation depending upon the magnitude of the operation.

An indication of capital costs in relation to size of feed and typical throughput is given in Table 16.

### Table 16
### Capital Costs

| Source | Model | Price, $ | Other, $* | Tph | Feed Size |
|---|---|---|---|---|---|
| Sortex | 621 M | 11,000 | 250 | 1 | 0.75 to 0.25-in. (19.0 to 6.4-mm) |
| '' | 711 M | 32,000 | 6,000 | 5 | 2 to 0.75-in. (5.1 to 1.9-cm) |
| '' | 811 M | 48,000 | 7,000 | 30 | 6 to 2-in. (15.2 to 5.1-cm) |

| Source | Model | Price, $/Tph | Capacity, Tph | | Feed Size |
|---|---|---|---|---|---|
| | | | Short | Metric | |
| Ore Sorters | 13 | 1,800 to 2,700 | 50 | 45 | 2 to 1.25-in. (5.1 to 3.2-cm) |
| '' '' | 13 | 1,300 to 1,900 | 70 | 65 | 3 to 1.25-in. (7.6 to 3.2-cm) |
| '' '' | 13 | 900 to 1,400 | 100 | 90 | 4 to 1.25-in. (10.2 to 3.2-cm) |

*Accessories, plus standby parts sufficient for 1 to 8 machines.

The cost of alterations to existing plant to accommodate sorting would have to be estimated separately, as would the over-all installation cost for the sorting equipment.

Some manufacturers prefer to offer their equipment on a long-term rental basis.

## Operating Costs

Contributing factors to total operating costs will be 1) power, 2) spare parts inventory, 3) repair and maintenance, and 4) operating personnel.

An indication of what operating costs will be is provided in Table 17.

Table 17
Operating Costs

| Source | Model | Power, $/hr (at 1¢ kW) | R & M, $/hr (parts and labour) | Operating Personnel, $/hr | Total, $/hr |
|--------|-------|------|------|------|------|
| Sortex | 621 M | 0.05 | 0.06 | 0.15 | 0.26 |
| " | 711 M | 0.19 | 0.31 | 0.25 | 0.75 |
| " | 811 M | 0.62 | 0.53 | 1.00 | 2.15 |
| " | 962 M | 0.05 | 0.05 | 0.25 | 0.35 |
| " | XR 21 | 0.05 | 1.00* | 0.25 | 1.30 |
| " | XR 11 | 0.09 | 1.00* | 0.25 | 1.34 |
| Gromax | GA 2x2 | 0.01 | | | |

| | | | | | $/Ton Ore** |
|--------|-------|------|------|------|------|
| Ore Sorters | 6 | | | | 0.15 |
| " " | 10 | | | | 0.08 |
| " " | 13 | | | | 0.075 |

*Maker recommends renewal of X-ray tube every 1000 hr; **For 0.75 to 6-in. (1.9 to 15.2-cm) feed.

With most sorting equipment, the cost for operating and supervision is variable. With the smaller units, once the system has been brought to optimum, very little attention is required and one operator can handle a battery of separators. In a small installation, one or two units, an operator could check the sorting periodically, while attending to other duties. With large units it may be necessary for an operator to keep an eye on the feed system, product removal, and on the sorting mechanism.

## EQUIPMENT AVAILABLE

Though a considerable number of machines have been developed most have not been built for sale, or have been discontinued as a commercial line. Some are available but not yet widely accepted. Certain machines have been developed for specific use and are not generally available; this is perhaps most notable in the diamond industry. New equipment is continually being developed. Up to the present the chief commercial producers of mineral sorting equipment have been Gunson's Sortex Limited, Ore Sorters (part of the RTZ group), and C.S.R. (Australia).

Table 18 accounts for the principal sorting units available at time of writing. Figures 31 to 37 illustrate some of these machines. The following descriptions will serve to show how the various elements are incorporated into an operational whole.

### GUNSON'S SORTEX 811M

This machine is designed to sort 2 to 6-inch feed. The feed is drawn from a surge bin by *vibrating feeder.* While in transit across the feeder, water sprays wash surface coatings from the pieces leaving the natural rock colours bright and fresh. Feed discharges from the vibrator onto an *aligning table* composed of a rotating disc, 5 feet

# Table 18
## Sorting Equipment

| Source* | Model | Presentation L = Single line S = Single layer | Sensing | Separation | Acceptable feed size | Feed preparation | Approximate Capacity tph | Power reqd. kWH | L | W | H | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sortex | XR 11 | S-Belt | X-ray | Air Blast | 1.25-in. to 7 mesh (32.0 to 2.8-mm) | Dry-damp | 2.0-7.0 | 3 | 7.5 | 2.5 | 6.0 | Includes shielding |
| " | XR 21 | L-2 Belts | " | " " | 0.375 to 14 mesh (9.5 to 1.2-mm) | Dry | 0.02-0.4 | 1.5 | 5.5 | 2.5 | 6.0 | Shielding & dust extractor |
| " | 962 M | L-Multiple Slide | Photometric | " " | 0.75 to 7 mesh (19.0 to 2.8-mm) | " | 0.5-3.5 | 1.5 | 4.5 | 2.5 | 6.0 | |
| " | 621 M | L-2 Belts | " | " " | 0.75 to 0.25-in. (19.0 to 6.4) | " | 0.3-2.0 | 1.3 | 5.5 | 2.5 | 5.0 | Dust extractor |
| " | 711 MW | L-Disc + Belt | " | " " | 2 to 0.75-in. (5.1 to 1.9-cm) | Water wash | 2.0-7.0 | 2.8 | | | | |
| " | 711 MD | L-Disc + Belt | " | " " | 2 to 0.75-in. (5.1 to 1.9-cm) | Dry | 2.0-7.0 | 2.8 | | | | Dust extractor |
| " | 811 M | L-Disc + Belt | " | " " | 6 to 2-in. (15.2 to 5.1-cm) | Water wash | 10-50 | 10 | 25.0 | 14.0 | 14.0 | |
| Ore Sorters 6 | | L-Cone + Belt | Radiometric | " " | 10 to 2-in. (25.4 to 5.1-cm) | Dry-damp | 15-55 | 4 | 23.0 | 12.0 | 10.0 | |
| " " | 10 HV | S-Slide | Conductivity | " " | 10 to 0.75-in. (25.4 to 1.9-cm) | Dry | 20-350 | 8 | 16.0 | 8.0 | 10.0 | |
| " " | 10 LV | S-Slide | " | " " | 10 to 0.75-in. (25.4 to 1.9-cm) | Dry-damp | 20-350 | 6 | 16.0 | 8.0 | 10.0 | |
| " " | 12 | S-Belt | Photometric | " " | 5 to 0.5-in. (12.7 to 1.3-cm) | " " | 15-220 | 5 | 16.0 | 10.0 | 10.0 | |
| " " | 13 | S-Slide | " | " " | 6 to 0.75-in. (15.3 to 0.9-cm) | " " | 10-120 | 5 | | | | |
| C.S.R. | Ore Sorter | L-Rolls | Infra-red | " " | 7 to 0.75-in. (17.8 to 1.9-cm) | " " | 60 | | 24.0 | 8.0 | 15.0 | Fuel oil 7 to 1 gph |
| C.S.R. | Fluorescence Sorter | " " . | U-V Fluorescence | " " | 7 to 1-in. (17.8 to 2.5-cm) | Water wash | 20-100 | 3 | 24.0 | 8.0 | 15.0 | |
| I.S.S.C. | Select-Ore | Rotary | Radio frequency permeability | " " | 2 to 0.5-in. (5.1 to 1.3-cm) | Dry | 20 | | 6.0 | 5.0 | 7.0 | |
| E.S.M. | G-3800R | L-Multiple Slide | Photometric | " " | 4 to 10 mesh (4.8 to 1.7-mm) | " | 1-2 | 1 | 5.0 | 3.5 | 7.5 | |
| Schwartz | X-SEPTA | S-Belt | X-ray | Fingers | 7 to 1-in. (17.8 to 2.5-cm) | Dry-damp | 30 | | | | | 12-volt battery |

*Gunson's Sortex Limited. Ore Sorters (Canada) Limited. The Colonial Sugar Refining Company Limited. International Sorting Systems Corporation. Electronic Sorting Machine Company. Schwartz Mining and Industrials Limited.
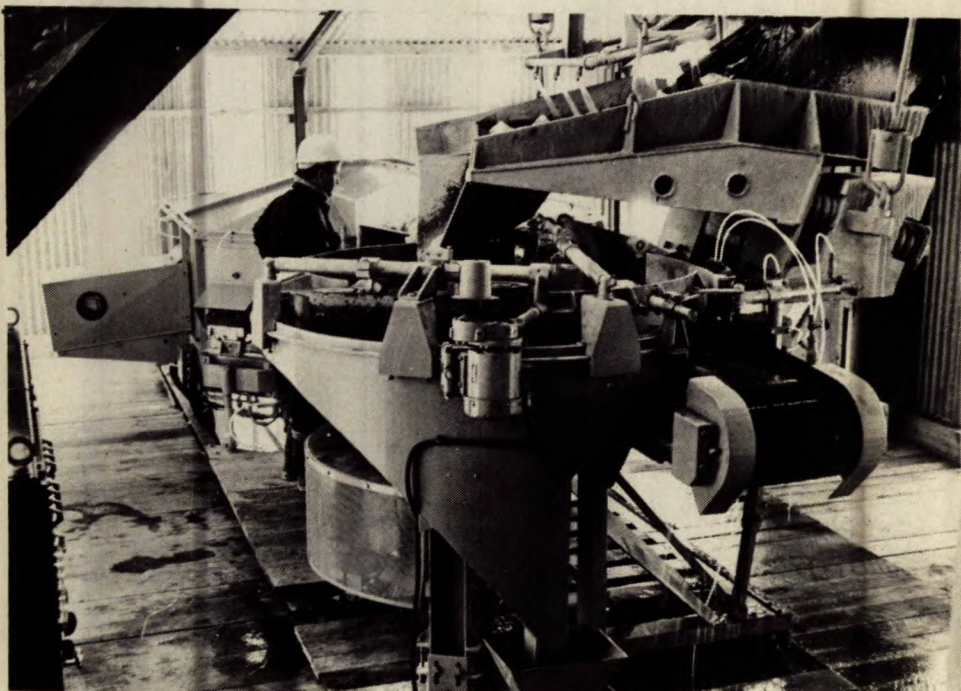
**Figure 31. Gunson's Sortex Ltd. 811M**

in diameter and fitted with special guide baffles. These baffles serve to damp tumbling or spinning, and to space the pieces so that they are discharged from the periphery relatively at rest and slightly apart. They fall onto the *main conveyor* belt which is 18-inches (45.7-cm) wide and travels at 300-ft/min (90-m/min). The pieces leave the aligning table at close to main conveyor velocity. The line they form is somewhat irregular but is within 6-inch (15-cm) of the conveyor centre. The main conveyor terminates after entering an opening in the optical chamber, and the pieces fall on a free trajectory through the *scanning point*. There is a belt scraper fitted below the main conveyor on the return run.

The *optical chamber* is an 8-foot (2.4-m) square by 5-foot (1.5-m) high steel box with a completely white interior. It is illuminated with four 1 kW quartz-iodine

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lamps mounted in ports at the corners of the chamber. By providing suitable baffles, the whole interior is evenly flooded with diffuse light. Two inspection cameras are mounted on opposite walls of the chamber on the outside so that they view the scanning point through glass covered ports. An air curtain keeps the ports clear of dust and moisture. The cameras also view the white interior walls, or appropriately located background strips, which establish the *comparison standards* for the sort. The entire interior may be washed down, as required, by means of suitably placed sprays.

The *cameras* are of the spot scan type. The *shutter* for each camera is an 8-inch (20-cm) aluminum disc with 16 equally spaced holes, each 0.040-inch (10-mm) in diameter, near its periphery. These discs are located so that the holes are behind the objective lens. A rotational speed of 3000 RPM has the effect of covering virtually the entire viewed surface with scan traverses. The *objective lenses* are f 3.5:75-mm, and they may be fitted with *filters* if required. Light passing the shutter holes is focused by a condensing lens onto the cathode of a *photomultiplier* with a built-in automatic gain control (to compensate for varying illumination, temperature, or shutter performance).

The electronic *control system* can be used to total the durations of the scans for size and the durations of the scans over areas of other than the desired colour for each piece of feed. The ratio of size area to off-coloured area is used in decision making, i.e., whether to accept or reject the piece. If the decision is to reject, a signal is relayed to the separation device. The duration of this signal depends upon the size of the subject feed piece; it activates an *air blast* timed to divert that piece. The electronic control system is built of rapidly interchangeable rack-mounted solid-state units. Stain-level discriminator adjustment, and stain to total surface area ratio selection, are provided. Either darker than desired, or lighter than desired, discolourations may be detected as required. The control system also uses a count of the number of pieces being scanned to regulate feed input.

The *separation system* is composed of ten 0.75-inch (19-mm) high-speed pilot-operated *solenoid valves,* in two banks of 5 each, one bank located 3-inches (7.6-cm) above the other. These are directed through individual nozzles to produce a combined thrust of 150-pounds (68-Kg). For large pieces, all 10 nozzles are used, for smaller pieces only 5. The system is located below the bottom of the optical chamber. Between 200- and 400-cfm (57- and 110-m$^3$/min) of 80 to 90 psi (5.6-Kg/cm$^2$ to 6.3-Kg/cm$^2$) air are required depending upon the number of rejections and size of rejected pieces. Air is routed to the nozzles via a receiver and a pressure vessel to avoid fluctuations. The machine requires 10 kW exclusive of power required for compressed air. It also requires water for spraying the feed and for washing the optical chamber.
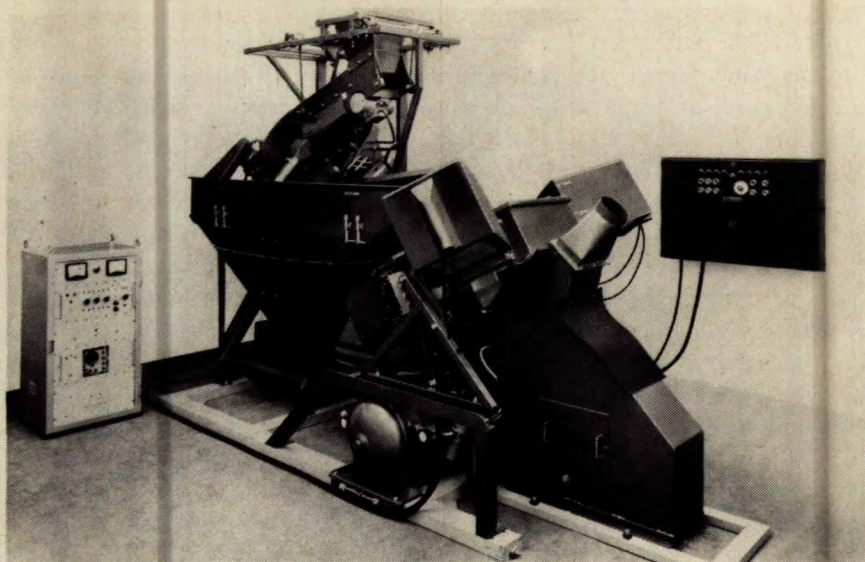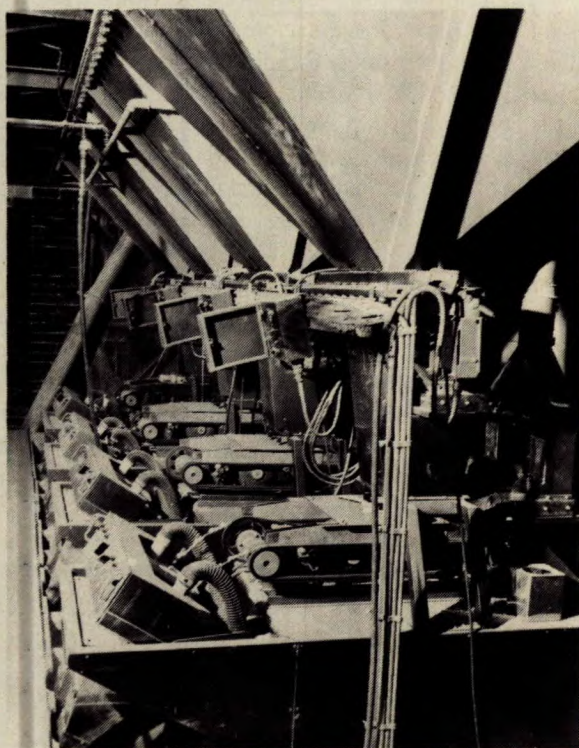
Figure 32. Gunson's Sortex Ltd. 711M



Figure 33. Gunson's Sortex Ltd. 621

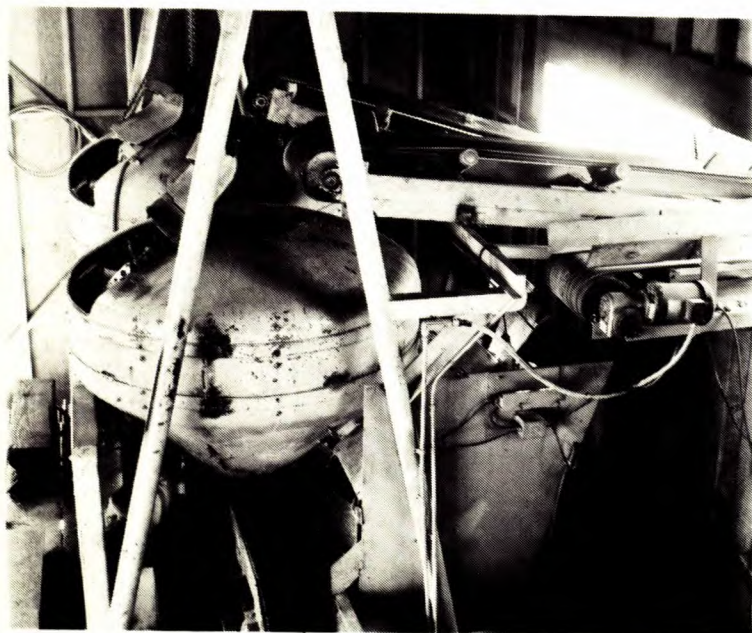Figure 34. Gunson's Sortex Ltd. XR11 and XR21



Figure 35. International Sorting Systems Corp. Select-Ore

## ORE SORTERS (CANADA) LTD., MODEL 10

This equipment uses the conducting ability of minerals for discrimination. It is available in a basic form which may be tailored to suit the specific situation. For processing dry, relatively low-conductance material, e.g., disseminated sulphides, the high-voltage (HV) type is used. For feeds which are good conductors, such as hematite, or for damp, porous material, the low-voltage (LV) type is used. Feeds ranging from 0.75 to 10-inch (1.9 to 25.4-cm) can be treated. Though material down to 0.375-inch (9.5-mm) can be handled, it is only economic for relatively high-value commodities due to capacity fall-off with finer feed. If required, pieces larger than 10-inch (25.4-cm) can be accommodated. Individual units are designed to accept roughly 0.75 to 2-inch (1.9 to 5.1-cm), 2 to 5-inch (5.1 to 12.7-cm), or 5 to 10-inch (12.7 to 25.4-cm) feeds.

Sized feed is drawn from a surge bin by a *primary vibrating feeder*. The rate is regulated by varying the amplitude of vibration. This discharges onto a *secondary vibrating feeder* which incorporates a grizzly section and a spreader section. Stray fines are thus removed and a single layer of feed is created for the presentation system.

The main feature of the *presentation system* is a *slide deck* set at minus 42.5 degrees. The deck is created from 10 stellite-6 bars, with side plates also of stellite. The deck surface is highly polished and machined to a plane, true to less than 10 micro-inches. It is a function of this deck to cause a smooth acceleration of the feed pieces, which have arrived at the top of the slide in a broad stream, and cause them to spread slightly apart. Ideally, there is no contact between pieces at the sensing point, so there will be accurate individual assessment. To achieve precision of both sensing and separation, it is very important that the acceleration be achieved with the pieces sliding rather than tumbling. The polished surface assists in this, and it is further aided by the damping effect of a light chain curtain under which the feed must pass as it enters the slide.

The *sensing system* is designed to detect electrical conductivity of the feed pieces and to locate the pieces in the feed stream. An equally spaced series of wound spring-wire electrodes, suspended above the slide deck close to its lower end, completely spans its width. The *electrode bar assembly* which supports them is suspended by hinged air cylinders at either side of the deck and attached to the main frame. This not only allows accurate positioning of the electrodes for height and attitude but provides for automatically clearing (and reducing damage to) the mechanism should a piece of tramp oversize be present in the feed. A trip bar, activated by such a piece, causes the feeder to stop, raises the electrode assembly, lets the piece pass, repositions the assembly, and restarts the feed. The mechanism may also be raised by an independent control for servicing.

When in operation, a potential is created between the electrodes and the grounded slide plate. If a feed piece is conductive, current will flow through it in proportion to its conductivity as it brushes the electrodes. The signal thus created is processed by the electronic control system.

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The *control system* is used to simultaneously process signals originating at any sensing location across the deck by means of individual *logic-control circuits*. A few milliseconds are required for information to reach the separation system. The action begins with the *primary sensing signal,* which is proportional to the conductivity of the subject rock fragment. The corresponding logic circuit amplifies the signal and compares it to a preset reference level above which the fragment is accepted. An accept decision activates a subsidiary circuit to generate a signal to the correct air-blast ejector. Interaction of the primary signal duration and a *pulse extension* governs the duration of air blast to match size of piece. All the electronics are modular, printed circuits mounted on plug-in circuit boards.

The air-blast *separation system* involves a series of narrow, equally spaced *slots,* across the slide deck. They are located slightly downstream from the sensing electrodes, just below the end of the deck, to channel the *air blasts* upward and outward. The system is so arranged that the normal width of the slide deck (48-inches, 1.22-metres) is covered by 20 to 30 complete elements, or channels, depending upon the feed size to be handled. Each channel includes three sensing electrodes, the necessary electronic circuitry, and an air blast slot. If a conducting rock fragment contacts the electrodes for only one channel, only the corresponding blast slot will fire. Should the fragment contact electrodes for more than one channel then corresponding blast slots will fire to ensure removal. The distance from electrodes to slots must be correctly adjusted for each feed to dovetail with controlled timing, and to position the piece correctly above the blast. High-speed pilot-operated solenoid valves control the air blast through each slot.

From 200- to 1200-cfm (5.7 to 34.0-m³/min) of air are required for separation depending upon size and type of feed processed. The HV system requires 8 kW and the LV 6 kW for all requirements other than air supply.
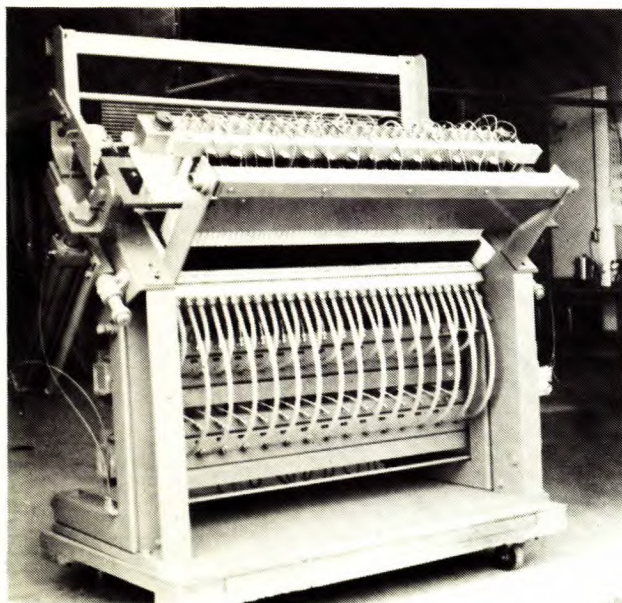


Figure 36.
Ore Sorters (Canada) Ltd.
Model 10

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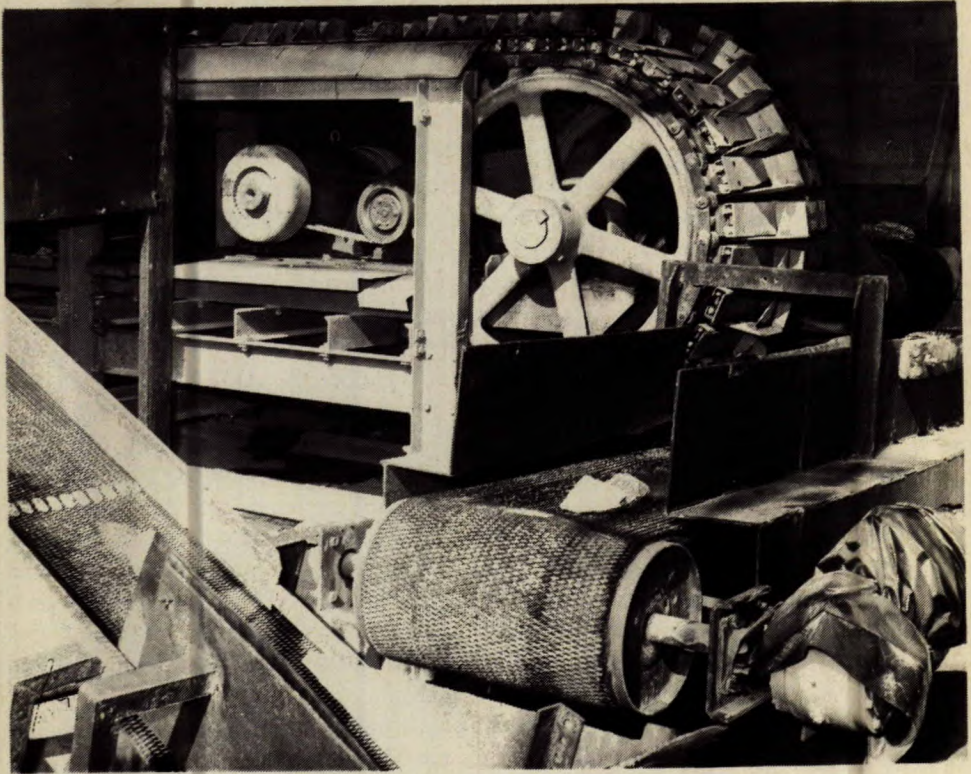
Figure 37. Gromax Inc. Limestone Sorter

# EXAMPLES OF SORTING

## OPERATING PLANTS

### Ojamo Mine, Finland

Blended limestone from various mining sources is processed with a Sortex 811 MW machine at a rate of 30 to 35 tph of 5.1 to 2.8-inch (13.0 to 7.0-cm) feed. The limestone contains up to 94 per cent $CaCO_3$. Due to climatic conditions, wet sorting is practised during summer and dry sorting during winter months. With wet sorting, over 95 per cent of the $CaCO_3$ is recovered at grades of 85 to 90 per cent $CaCO_3$. During dry sorting, abraded powder tends to mask rock colouring, but the recovery remains above 95 per cent, though the grade drops to between 80 and 88 per cent $CaCO_3$. Operating costs are approximately 7 cents per ton of feed.

### Ojibway Mine, Canada

Rock salt and anhydrite are separated in two stages with Sortex 621 equipment. Feed is 0.625 to 0.5-inch (16.0 to 12.7-mm) and passes the first bank of machines at approximately 1 tph per unit. Concentrate from the first bank feeds the second bank at approximately 0.7 tph per unit. The recovery of halite is 80 per cent, and the product is 99.98 per cent soluble.

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## Texas Architectural Aggregates, Inc., U.S.A.

A variety of products from quartz, marble, and granite are derived through electronic sorting with Gromax equipment. Though material as fine as 0.125-inch (3.17-mm) can be processed, that most commonly treated is 0.5 to 0.25-inch (12.7 to 6.35-mm), and coarser sizes can be handled. Unwanted material, about 15 per cent of feed, is reduced to close to 1 per cent in product at a sorting rate of 0.5 tph.

## Uranium Mines

Two Ore Sorters Model 6 units were put in service at Bicroft Uranium Mines Limited, Canada, in 1958. This plant was designed to process 50 tph of 8 to 2.5-inch (20.3 to 6.3-cm) feed; about 66.7 per cent was rejected for a loss of 3.3 per cent of the $U_3O_8$. Plant throughput was increased by 300 tpd with preconcentration by sorting. Sorter operating costs amounted to 23 cents per ton of sorter feed.

A four-unit Model 6 installation was put in service at Mary Kathleen Uranium Ltd., Australia, in 1960. The plant was designed to sort 140 tph of 6 to 3-inch (152 to 7.6-cm) feed; it rejected, on average, 38.9 per cent for a loss of 3.5 per cent of the $U_3O_8$. Plant throughput was increased by 600 tpd with sorting. Operating costs amounted to 13 cents per ton of sorter feed.

Four Model 6 units were installed at Eldorado Mining and Refining, Beaverlodge, Canada, in 1961. The plant was designed to process 80 tph of 6 to 3-inch (15.2 to 7.6-cm) feed; about 50 per cent was rejected for a loss of 2.0 per cent of the $U_3O_8$. Operating costs were approximately 24 cents per ton of sorter feed.

## British Plaster Board Company, England

The objectionable material is marl, varying from red to green in colour. Feed is divided into sizes, 1.5 to 0.75-inch (3.8 to 1.9-cm), 0.75 to 0.375-inch (19.0 to 9.6-mm), and 0.375 to 0.25-inch (9.6 to 6.2-mm). Each size is treated with separate Sortex units at 2.0, 1.2, and 0.5 tph respectively per unit. High-quality gypsum is produced.

## Cagliari, Sardinia

A solar salt plant is using Sortex 962M equipment to eliminate contamination and produce a pure white product.

## Commercial Mining, Industrial and Shipping Company, Greece

Thirty-five machines have been acquired to upgrade magnesite, chiefly in the 2.37 to 1.125-inch (6 to 3-cm) size.

## Cementa AB, Sweden

Two Sortex 811M machines are used to separate flint from chalk which is used for lime production. Each handles a minimum of 50 tph of 6 to 3-inch (15.0 to 8.0-cm) feed.

## Kola Peninsula, USSR

Two Sortex machines, an 811M and a 711M, have been installed on the Kola Peninsula to sort feldspar.

## King Island, Tasmania

A fluorescence sorter, developed by C.S.R. Research Laboratory, is concentrating scheelite from an ore at King Island, in the Bass Strait, between Australia and Tasmania.

## Other Operating Plants

Sortex equipment is in operation on the Isle of Skye, Scotland, for the production of white marble and in Vermont for upgrading marble. There are numerous installations of Sortex equipment for both prospecting and final sorting of diamonds.

Ore Sorters Model 13 equipment is in operation in Africa for gold ore concentration.

International Sorting Systems Corporation installed a 100-tph plant in Michigan, in 1970, for isolating ore containing native copper.

## EXPERIMENTAL SORTING RESULTS

| Material | Problem | Results |
|---|---|---|
| Asbestos | Concentrate the fibre-bearing pieces from a Canadian asbestos ore in 2.5 to 1-in. (7.4 to 2.5-cm) size range. | Separation with an Ore Sorters Model 10 collected 89.9% of the fibre in 55.2% of the feed weight. |
| Barite | Remove barite from siliceous waste in a mixture varying from white through yellow and green to brown in the 0.62 to 0.375-in. (16.0 to 9.5-mm) size range. | Two passes through a Sortex 621M machine removed first the white barite then the buff barite. The white product ran 95.2% $BaSO_4$, the buff 91.1% $BaSO_4$. |
| Brucite | Remove dark, high-$SiO_2$ pieces from light, lower-$SiO_2$ pieces of brucite ore in the 2 to 1-in. (5.1 to 2.5-cm) size range. | Separation by Sortex 711M at 5 tph isolated 63% of the weight at 2.38% $SiO_2$ from a 7.01% $SiO_2$ feed. |
| Calcite | Recover filler grade calcite by removing hornblende gneiss in the 0.5 to 0.375-in. (12.7 to 9.5-mm) size range. | Separation on Sortex 621M equipment recovered 66.4% of the feed at a brightness of 98.5%. |
| Calcite | Separate white calcite from dark siliceous material in 0.75 to 0.5-in. (1.9 to 1.3-cm) size range. | Sorted in two stages with Sortex equipment. Primary run at 1.6 tph. Secondary run at 1.6 tph. Recovery, 76% of feed weight at 43.8% CaO. |
| Chalk | Remove dark flint from chalk in the 0.75 to 0.5-in. (1.9 to 1.3-cm) size range. | A single pass through Sortex equipment at 0.8 tph recovered 97.5% by weight with a content of 0.46% flint. |
| Copper | Preconcentrate the copper from a Canadian ore in the 4 to 0.75-in. (10.2 to 1.9-cm) size range. | Separation with Ore Sorters Model 10 collected 97.7% of the Cu in 28.26% of the feed weight. |

| Material | Problem | Results |
|----------|---------|---------|
| Copper | Preconcentrate the copper from a Canadian ore in the 4 to 0.75-in. (10.2 to 1.9-cm) size range. | Separation with Ore Sorters Model 10 collected 94.1% of the Cu in 32.8% of the feed weight. |
| Copper | Separate pieces containing native copper from copper-free pieces. | The ISSC method of radio frequency permeability was applied to several sizes of feed. Up to 61% of the Cu was recovered in 13% of the feed weight. This may be improved by adding untreated fines, etc. |
| Copper | Recover copper values from a magnetic iron plant waste at plus 0.5-in. (12.7-mm) size. | Separation with Ore Sorters Model 10 recovered 70% of the Cu in 11% of the feed weight. |
| Copper-Nickel | Preconcentrate the copper and nickel from a Canadian ore in the 4 to 0.75-in. (10.2 to 1.9-cm) size range. | Separation with an Ore Sorters Model 10 collected 97.9% of the Ni and 97.5% of the Cu in 74.4% of the feed weight. |
| Copper-Silver | Preconcentrate the copper and silver from an Australian ore in the 8 to 0.375-in. (20.3 to 0.9-cm) size range. | Separation with an Ore Sorters Model 10 collected 98.9% of the Cu and 98.0% of the Ag in 61.6% of the feed weight. |
| Diamonds | Recover diamonds from 1.25 to 9 mesh (33.0 to 2.0-mm) gravel concentrates. | Separately processing sized fractions with Sortex XR 112B equipment will recover 98 to 100% of the diamonds at rates of 28 to 38 tph depending upon feed size. |
| Dolomite | Produce glass grade dolomite by removing iron-stained pieces from 2 to 1.25-in. (5.1 to 3.7-cm) material. | Separation by Sortex 711M at 5.1 tph recovered from 18.6% of the feed at 0.06% $Fe_2O_3$ to 56.0% at 0.08% $Fe_2O_3$ depending upon the settings used. |
| Feldspar | Recover potash feldspar from a "quarry waste" containing quartz, discoloured feldspar, and some mafic minerals in the 0.5-in. to 3-mesh (12.7 to 6.7-mm) fraction. | The dark and discoloured pieces were removed in one pass through a Sortex 621M machine. Quartz was separated from feldspar in a second operation to produce a product analyzing 66.0% $SiO_2$, 18.9% $Al_2O_3$, 12.6% $K_2O$, 2.0% $Na_2O$, and 0.015% $Fe_2O_3$. |
| Gold | Preconcentrate gold from a South African source by removing waste rock from vein material in the 0.5 to 0.375-in. (12.7 to 9.5-mm) size range. | By sorting the feed in two stages with Sortex equipment it was possible to recover 85.8% of the gold in the primary stage at 23.6 ppm gold, and 12.9% in the secondary stage at 7.1 ppm gold. The reject contained 1.3% of the gold and represented 34.2% of the feed. |

| Material | Problem | Results |
| --- | --- | --- |
| Gypsum | Concentrate gypsum from a plant waste containing white, grey, brown, and black gypsum with grey-green shale and grey to black carbonate in the 0.75 to 0.5-in. (19.0 to 12.7-mm) size range. | One pass through a Sortex G526 machine produced a product containing 82% gypsum with a recovery of 84%. |
| Gypsum | Concentrate gypsum in the 0.75 to 0.25-in. (19.0 to 12.7-mm) size range. | By separately sorting in three sizes from 1 to 3 tph with Sortex 962M equipment, acceptable gypsum was recovered representing 60% of the feed. |
| Ilmenite | Remove greyish green feldspar from black ilmenite in 3 to 4-mesh (6.7 to 4.8-mm) size. | One pass through a Sortex 621M machine recovered 87% of the feed at sp gr 4.56. |
| Lepidolite | Isolate dark purple lepidolite from lighter-coloured, lower-grade material in the 0.5 to 0.375-in. (12.7 to 9.5-mm) size range. | One pass through Sortex equipment at 1 tph recovered 76% of the lepidolite at 3.54% $Li_2O$. |
| Lepidolite | Reduce the lepidolite content of a 0.375-in. to 3-mesh (9.5 to 6.7-mm) pegmatite feed. | To remove the light to dark purple lepidolite it was necessary to make two runs with Sortex 621M equipment. The first isolated an 80% lepidolite product and the second a 45% product. The light fraction was virtually lepidolite free. |
| Limestone | Remove sandstone from limestone on material from a Canadian source in the 0.75 to 0.375-in. (19.0 to 9.5-mm) range. | Single passes of sized fractions through a Sortex 621M machine recovered over 80% of the $CaCO_3$ as a 98.6% product from an 80% $CaCO_3$ feed. |
| Limestone | Recover white limestone from mixed white and grey cobs 5 to 2.5-in. (12.7 to 6.4-cm) in size. | One pass through a Sortex 811MW machine at 25 to 30 tph recovered 65 to 70% of the feed as a product containing 92 to 94% $CaCO_3$, 0.30 to 0.35% $MgCO_3$, and 0.06 to 0.08% $Fe_2O_3$. |
| Limestone | Recover white limestone from mixed white, yellow, pink, and light grey in the 5 to 2-in. (12.7 to 5.1-cm) size range. | Treating two sizes of feed separately with Sortex 811MW equipment at 22 to 35 tph recovered 90 to 95% of the feed at 85% $CaCO_3$. |
| Magnesite | Isolate cryptocrystalline magnesite in the 0.375-in. to 4-mesh (9.5 to 4.8-mm) size range. | An acceptable product was obtained by rejecting up to 50% of the feed weight with Sortex 962M equipment at 0.75 tph. |

| Material | Problem | Results |
| --- | --- | --- |
| Malachite | Separate malachite from limestone in the 0.5 to 0.25-in. (12.7 to 6.4-mm) size range. | Separation by Sortex 621M at 0.75 tph concentrated 82.8% of the Cu in 38% of the feed weight. |
| Quartz | Separate iron-stained quartz from white quartz in the 0.75 to 0.375-in. (19.0 to 9.5-mm) size range. | One pass through Sortex equipment at 1.2 tph placed 60.5% of the feed in concentrate with 1.4% stained grains, leaving a reject containing 78.4% stained grains. |
| Salt | Improve the quality of solar salt by removing undesirable material in the 0.5-in. to 6-mesh (12.7 to 3.4-mm) size range. | An acceptable product was obtained by rejecting 2 to 3% of the feed with Sortex 962M equipment at 1.6 tph. |
| Salt | Isolate rock salt from Germany in the 0.5 to 0.375-in. (12.7 to 9.5-mm) size range. | An acceptable product was obtained by rejecting 45% of the feed weight with Sortex 962M equipment at 1.75 tph. |
| Scheelite | Preconcentrate scheelite from Austria. | It was found possible to recover 95 to 97% of the $WO_3$ in 10 to 13% of the weight from 2.5% $WO_3$ feed with Sortex 711M equipment. |
| Scheelite | Preconcentrate scheelite from Japan. | It was found possible to recover 75 to 86% of the $WO_3$ in 20 to 30% of the weight using 0.5% $WO_3$ feed, and 78 to 90% of the $WO_3$ in 20 to 40% of the weight using 2.0% $WO_3$ feed, with Sortex 711M equipment. |
| Scheelite | Preconcentrate scheelite from France. | It was found possible to recover 62 to 74% of the $WO_3$ in 30 to 40% of the weight from 1.0% $WO_3$ feed with Sortex 711M equipment. |
| Sulphides | Preconcentrate sulphides from South American ore in the 3 to 0.75-in. (7.6 to 1.9-cm) size range. | Separation with Ore Sorters Model 10 collected 94.2% of the Pb, 92.8% of the Zn, 86.8% of the Cu, and 94.3% of the Ag, in 60.5% of the feed weight. |
| Sulphides | Preconcentrate sulphides from an Australian ore in the 2 to 0.75-in. (5.2 to 1.9-cm) size range. | Separation with Ore Sorters Model 10 collected 97.2% of the Pb, 97.9% of the Zn, 88.4% of the Cu, 97.6% of the Ag, and 95.2% of the Au, in 36.5% of the feed weight. |
| Talc | Concentrate pale green talc pieces from a mixture of talc and greenish-grey chlorite in 0.5 to 0.25-in. (12.7 to 6.4-mm) size range. | It was possible to isolate the talc with a Sortex 621M machine with a product brightness of 90%. |
| Talc | Isolate platy talc in the 0.375 to 0.25-in. (9.5 to 6.4-mm) size range. | An acceptable product was obtained with a Sortex 962M machine at a rate of 1.0 tph. |

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| Material | Problem | Results |
|----------|---------|---------|
| Trona | Remove dark, low grade pieces from light, high grade pieces of trona in the 1.25 to 1.0-in. (3.8 to 2.5-cm) size range. | Separation by Sortex 711M at 4 tph concentrated 53.1% of the feed with 0.8% insoluble from the 8.3% insoluble feed. |
| Uranium | Preconcentrate uranium from a Canadian ore in the 0.5-in. to 6 mesh (12.7 to 3.5-mm) size range. | Single passes in several sizes through Sortex 621M equipment removed 27.4% of the feed weight with a loss of 7% of the $U_3O_8$. Rerunning each size gave a total removal of 42% of the feed weight for a loss of 12.7% of the $U_3O_8$. |
| Uranium | Preconcentrate the uranium present in a minus 12-in. (30.5-cm) feed and produce a low value discard. | By removing minus 1-in. (2.5-cm) fines and separately sorting sized fractions with the Lapointe Picker, 51.7% of the feed was discarded with a loss of 3.7% of the $U_3O_8$. |
| Uranium | Preconcentrate $U_3O_8$ from plus 3-in. (7.6-cm) ore. | Separation with Ore Sorters Model 6 collected from 91.0% of the $U_3O_8$ in 56.8% of the feed weight to 98.5% of the $U_3O_8$ in 80.1% of the feed weight depending upon the settings used. |
| Uranium | Preconcentrate $U_3O_8$ from plus 2-in. (5.1-cm) ore. | Separation with Ore Sorters Model 6 collected from 69.8% of the $U_3O_8$ in 22.1% of the feed weight to 92.6% of the $U_3O_8$ in 44.6% of the feed weight depending upon the settings used. |
| Uranium | Beneficiation of ore from Elliot Lake, Ont. | Experiments with a translucency detector[23] indicate a loss of 10 to 15% of the uranium in rejecting 35 to 40% of the feed. |
| Vanadium | Preconcentrate vanadium from a quartzite, feldspar, iron oxide and montmorillonite feed ($V_2O_5$ in the last two) in the 0.625 to 0.25-in. (16.0 to 6.4-mm) size range. | Montmorillonite removed by washing. Iron oxides isolated by Sortex 621M at 1 tph to concentrate 88.5% of the $V_2O_5$ in 40.8% of the feed weight. |

Although there are many examples, the above provide a cross-section of sorting possibilities. It should be noted that photometric sorting will produce very pleasing colour combinations from either mineral chips or gravels for use in exposed aggregate or terrazzo.

# TRENDS

In this comparatively new and highly dynamic field, developments spring from inventive sources like sparks from a grinding wheel — applied science in action. A

combination of hard work, up-to-date knowledge, and belief in sorting as a potent mineral winning tool is represented. In the van are Gunson's Sortex, Ore Sorters (Canada) Ltd., Colonial Sugar Refining, and the Royal School of Mines Sorting Research Group. All organizations shown under Table 1-A are, however, more or less active.

At present, the limitations to electronic sorting are basically mechanical. A notable gap in the technology is the inability to separate minus 0.25-inch (6.4-mm) particles at a speed high enough to achieve desirable capacity. Accelerated presentation systems, improved sensing accuracy, and ultra-high-speed separation methods are required. The gap is rapidly being filled, and it is anticipated that these improvements will apply to the coarser sizes of feed as well.

Sensing methods under examination, other than those previously dealt with, include the magnetic properties of minerals, magnetic eddy currents, metal detection devices, and high-sensitivity infrared.

An area which offers some future promise is that of coating, or staining, to enhance separation properties. Mathews[18] has patented a method of staining to render specific minerals fluorescent. A method for selectively staining feldspar to facilitate photometric distinction from quartz has been developed by the Royal School of Mines group in collaboration with Gunson's Sortex. Ore Sorters (Canada) Ltd. indicate that copper sulphate, sodium sulphide, and similar chemicals will enhance the conductance of sulphides, oxides, or carbonates.

Progress is being made on the development of recycling systems. Sorting equipment plays a notable role, particularly in the reclamation of bottle glass.

Mineral dressing arts are turned into science through knowledge and understanding of the principles involved, and their application to the problem. This conversion is being assured for electronic sorting by research activity in many parts of the world. As an example, a group at the Royal School of Mines, London, England, worked on the following sponsored developments from 1968 to 1970: 1) an automatic spectrophotometer for analyzing the light reflected from mineral surfaces, 2) electronic delay units to enhance the duration and accuracy of separation timing, 3) time-period analyzers to accurately determine particle speeds and spacing, 4) accuracy testing of optical sensors, 5) valve and nozzle analysis for air blast units, 6) multi-channel presentation methods, and 7) mathematical models for sorting systems.

Theoretically there are few limitations to mineral separation by sorting. Mechanical and economic road blocks, existing and future, will be circumvented to meet the need.

The real destiny of selective sorting may well be in association with, or as part of, the high-capacity continuous excavators. A system of this nature would require minimum movement of waste from its source.

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# GLOSSARY

*Accept* — generally denotes feed pieces not diverted, or separated, from the main stream.

*Air blast* — a short burst of compressed air used to divert selected pieces from the feed stream.

*Background* — a reflecting surface used to establish constant output from a phototube.

*Concentration* — bringing together feed pieces of similar composition to the exclusion of others.

*Conductivity* — the ability of a mineral to conduct electricity.

*Detection* — see Sensing.

*Discrimination* — see Sensing.

*Diffuse reflectance* — random light, or scattered, reflectance.

*Ejection* — deflection of pieces from the feed stream.

*Electronic sorting* — the separation of composite materials into component parts by means of devices based upon electronic systems.

*Emission* — emanation of alpha, beta or gamma radiation, or other energy forms.

*Fluorescence* — visible light caused by emission of photons.

*In-line* — single pieces following closely behind each other.

*Liberated* — feed pieces composed of one mineral, or a desirable combination of minerals.

*Mineral sorter* — an electronic sorting device for separating mineral composites into components.

*Middling* — a feed piece containing both desirable and undesirable components.

*Photometric* — based on light, or light intensity.

*Polarized* — fixed, or unidirectional, light.

*Presentation* — the means by which feed pieces are removed from storage, oriented, and delivered in an acceptable fashion to the sensing area.

*Preconcentration* — upgrading feed by the removal of unwanted pieces.

*Radiometric* — based on natural radioactivity, or self-emitted radiation.

*Reflectance* — the ability of a mineral to return light directed onto its surface.

*Reject* — generally denotes the feed pieces diverted, or separated, from the main stream.

*Salvage* — extracting some economic advantage from material normally considered uneconomic to work.

*Scanning* — the examination of feed pieces by a sensing device.

*Scintillometer* — a device for detecting ray emissions.

*Sensing* — the means of identifying a property, or properties, which will distinguish specific mineral pieces from others in a composite.

*Separation* — division into component parts.

*Single line* — see in-line.

*Single layer* — a stream of pieces one piece thick.

*Solenoid* — a small electromagnet.

*Sortability* — whether a specific feed may be profitably separated into its components or not.

*Sorting* — see electronic sorting.

*Spectral reflectance* — direct, or ordered, reflectance: mirror-like.

*Transparence* — the ability of a mineral to transmit light directly through itself.

*Translucence* — the ability of a mineral to transmit light indirectly through itself.

*Viewing* — see scanning.