İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

SORTING OF FLUORESCENT MINERALS BY USING A MULTI SENSOR SORTER (MIDAS)

M.Sc. Thesis by
Evren ÖREN

Department : **Mining Engineering**

Programme: **Mineral and Coal Processing**

AUGUST 2007

İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

SORTING OF FLUORESCENT MINERALS BY USING A MULTI SENSOR SORTER (MIDAS)

M.Sc. Thesis by
Evren ÖREN

505031102

Date of submission : 7 May 2007

Date of defence examination: 13 June 2007

Supervisor (Chairman): Prof. Dr. Fatma ARSLAN

Members of the Examining Committee Prof.Dr. Ercan AÇMA

Assist. Prof.Dr. Alim GÜL

AUGUST 2007

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

COK SENSORLÜ BIR AYIRICININ (MIDAS) FLORESANS MINERALLERE UYGULANMASI

YÜKSEK LİSANS TEZİ

Mad. Müh. Evren ÖREN

505031102

Tezin Enstitüye Verildiği Tarih : 7 Mayıs 2007

Tezin Savunulduğu Tarih : 13 Haziran 2007

Tez Danışmanı : Prof. Dr. Fatma ARSLAN

Diğer Jüri Üyeleri Prof.Dr. Ercan AÇMA

Assist. Prof.Dr. Alim GÜL

AĞUSTOS 2007

PREFACE

Particular thanks to Prof. Dr. –Ing. Hermann Wotruba for his idea about fluorescence sorting and giving me the chance of producing a work based on the idea.

Special thanks to Prof. Dr. Güven Önal and Prof Dr. Neset Acarkan making his best to arrange the conditions between Istanbul Technical University and University of Technology Aachen also letting me to study in Aachen.

I am very grateful for the assistants in Aachen especially, Dipl.-Inform. Thomas Scharrenbach for sharing his unique knowledge and giving fruitful helps.

I would like thank to Dipl.-Ing. Maryam Delavarian and Prof. Dr. Fatma Arslan for supervising me the whole study and their endless support in every stage.

Thanks to Heiko Lischka, and all technical workers in AMR that he solved every problem occurred with patient and endless working willness.

Very lovely thanks to beautiful person Ece Kavlak, and my family who supported me in every condition and situation.

AUGUST, 2007 Evren Ören

CONTENTS

ABBREVIATIONS

UV : Ultra Violet
MIDAS: Multi Detector Array Sorter
AMR : Aufbereitung von Mineralische Rohstoffe
ROM : Run of Mine

LIST OF TABLES

LIST OF FIGURES

Page

ÇOK SENSÖRLÜ BİR AYIRICININ (MIDAS) FLORESANS MİNERALLERE UYGULANMASI

ÖZET

Bu çalışma çeşitli minerallerin yüzeysel (renk, floresans) özelliklerini kullanarak, otomatik ayırılma olanaklarını araştırmak için yapılmıştır.

Mineral olarak floresans özellikleri ile tanınan Florit ve seelit seçilmiştir.

Deneyler Almanya'nın Aachen kentinde bulunan Aachen Teknoloji Üniversitesi, Cevher Hazırlama labaratuvarlarında yapılmıştır ve çok sensörlü bir elektronik ayırıcı olan MIDAS kullanılmıştır.

MIDAS aletinde kizil ötesi, metal detektörü, optik kamera, UV kamera ve 3D kamera olmak üzere beş adet sensör bulunmaktadır.

Numunelerde 4 sensör denenmiştir. Metal detektörü ve kızıl ötesinden her hangi bir sonuç alınamamıştır. 3D kameranın kullanılması için bir neden görülememiştir.

MIDAS'da halihazırda bulunmayan UV ışık ve bu ışık beraberinde gerekli olan soğutma düzeneği makineye eklenmiş ve software ile uyumu sağlanmıştır. UV ışının etrafına verdiği zararlı ışınlardan korunmak için makineye yeni bir hayne imal edilmiştir.

Seelit ile yapılan deneylerde konsantre ile atık arasında herhangi bir renk farkı bulunmadığı için optik aıyrıcı sonuç vermemiştir. UV kamera ise floresans olan numuneleri ayırmada başarılı sonuçlar vermiş ve konsantre ile atığı ayırmıştır.

Florit ile yapılan deneylerde optik kamera konsantreyi tanımlamış ve başarılı bir ayırma gerçekleştirmiştir. UV kamera floresans ışığı altında florit ve yantaşları arasında herhangi bir yansıma farkı sezmemiş, bu yüzden başarılı bir ayırma sağlanamamıştır.

Çalışma sonunda iki mineralinde otomatik ayırıcı ile ayrılması sağlanmış ve endüstri açısından önemli bir adım atılmıştır.

SORTING OF FLUORESCENT MINERALS BY USING A MULTI SENSOR SORTER (MIDAS)

SUMMARY

The aim of this study is using new sorting methods for two different minerals, fluorite and scheelite. These two belong to fluorescent minerals. The aim is to use different properties of each of them and try to find a sensor which makes possible to sort them. For this reason the newest multi sensor sorter which exists and situated in the department of mineral processing (AMR) of the Technology University of Aachen (RWTH-Aachen) was used.

This machine is able to sort particles based on the color, brightness and transparency (line scan color camera), fluorescence (UV camera), electrical conductivity (metal sensors), dimension (3D camera) and heating conductivity (infrared camera).

As MIDAS didn’t have any UV lamb, it has been added to the machine and the connection between the new system and software has been done. Because of harmful rays from the UV lambs a new housing is made for the machine.

For fluorite and scheelite efficiency of each of these sorters were studied and when necessary, the combination of two or more sensors’ effect on the result of the sorting are investigated.

The studies with scheelite samples didn’t get any success with optical sorting as the colors of the concentrate and the tailings were almost the same. The experiments with the fluorescence sorter were succeeded, the fractions were successfully sorted.

Fluorite samples were easily sorted by the color sorter. The fluorescence exciting of both tailing and concentrate were almost the same so the UV sorter couldn’t distinguish the both fractions.

To summarize the both samples were successfully automatic sorted and the study made a pre-step for application in the industry.

1. INTRODUCTION

1.1. Sensor Based Sorting

Ore sorting depending on the surface properties of the material is one of the oldest methods in mineral processing field Hand sorting used by the earliest metal workers several thousand years ago and still in practice at some of the mines especially for run-of-mine ore [1]. But as the technology develops and the man power gets more expensive, not only mineral producers but also every type of industry start to search for more automated ways to improve their productiveness and their operation costs.

The idea lying under developing automated sorter machines is not very different than the thirst for artificial intelligence, but in this case the cameras take the place of human eyes, and the air valves start to do the picking instead of human hands. But for coordination instead of human brain, the state of art of our lives, the computers take place.

Electronic sorting is relatively a new method in mineral processing field but this technology actually has the roots till Madame Curie found X-Ray and her X-Ray attenuation – based potato/clod sorter. In 1898 an instrument *Carboscope* provided X-Ray attenuation images from coal products and said to be might helpful for coal preparation. The practical use of X-Ray attenuation technology was in 1960s as fully automated potato/stone sorter, and developed into a coal/waste sorter subsequently [2]. The first sorter used commercially was probably “Electric Sorting Machine” of Lowell, in Michigan, which sorted peas using optical discrimination in the year 1931. In 1960s sorters didn’t have the necessary interest from the minerals field exception of diamond producers, but found place and reputation in the food industry in those years.

Making an overview, today’s sorter usage in minerals’ industry unfortunately is not more hopeful than those years. In the article entitled as “Sensor sorting technology - is the minerals industry missing a chance?” written by Wotruba (2006) mentions that the usage of the sorters in the recycling field are even more than those in mineral processing plants worldwide. He has mentioned that the 2000 German plastic recyclers have installed about 400 NIR (Near Infra Red) Sorters and during that time about 100 Sorters (excluding the numbers for diamonds) have been commissioned for mineral processing applications around the world.

Current sensor technologies available for mineral processing are [3; 4]:

- Optical Sensors for visible light
- Optical sensors for weak visible light detection (for fluorescent minerals)
- Infrared sensors
- X-Ray sensors
- Metal detectors
- Radioactivity (Radiometric) sensors

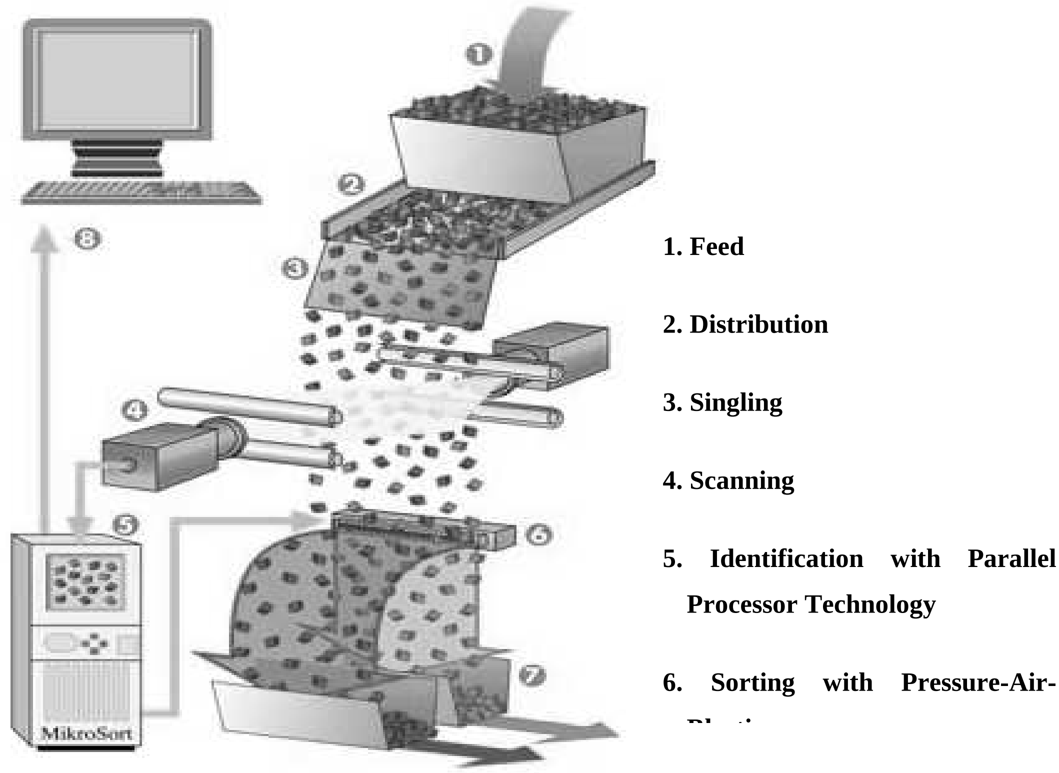
and also for laboratory and pilot scale:

- LIF (Laser induced fluorescence) sensors
- LIBS (Laser induced breakdown spectrometry) sensors

2. 1.1.1. Optical Sensors

Optical sorting is the backbone of the sensor based sorting devices and it will always remain, either alone or combined with the other sensors. Most of the sorter applications in the mineral industry are the ones with the optical cameras [5].

As a rough description of mechanism, the particles are first recognized by the cameras while they are on the conveyor belt or after departing the belt, when they begin to fall (forming a ballistic curve or free fall). The data from the cameras are sent to computer for identifying the object with the installed data analyzing program. Depending on this identification with defined parameters the particle would be blasted by the air valves or it would be left to do its own natural movement. In Figure 1.1 the working principle of an optical sorter (MikroSort®) from Mogensen GmbH-Germany is illustrated [6].



FigureError! No text of specified style in document.**.1:** MikroSort® Mogensen GmbH-Germany [6]

The sorting is possible with the line scan cameras, if the ore and tailing can be differentiated by color, brightness, reflection or transparency. For an effective sorting mostly the particles should be above 10 mm screen size and the surface of the particles should be clean enough for a sharp identification. For those reasons as preprocess, use of water for washing/scrubbing which can be combined with screening off undersize can be applied. Moist surfaces mostly help the process, and make the identification easier and more effective [5].

Optical sorting is a common process and used in many mines although with optical sensors, only the optical properties on the material surfaces can be identified. As a matter of fact that the under layer of surface and the bottom of the particle remains unrecognized by the cameras [4]. Figure 1.2 helps to understand the determination better.

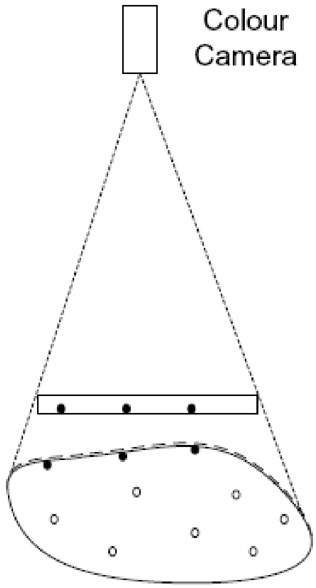


Figure Error! No text of specified style in document.**.2:** Schematic of optical sensor [4]

The camera above is able to see the top surface of the particle and identifies the 3-dimensional object as 2-dimensional picture or color groups. To avoid problems which could occur, like missing the sides of the particle and making false identification, most of the times especially in the industrial applications two cameras are used instead of one camera. These cameras are installed in order to capture a full view from both sides of the particle but unfortunately some parts of the particle would remain without assignment with most of the sorters that are applied.

3. 1.1.2. Metal Sensors

One of the sensors mostly used after cameras are *"metal detectors"* that mainly work in order to detect the electrical conductivity of the particles, so ore which contains some or one of the base metal minerals might be detected and identified. In Table 1.1 some of the minerals' electrical conductivities are shown [3].

Table Error! No text of specified style in document.**.1:** Electrical conductivity values for some minerals [3]

Mineral	Electrical Conductivity (ohm-m)
Insulators	
Quartz	3.8×10^{10} - 1.2×10^{12}
Calcite	5.5×10^{12}
Amphibole	10^{7}
Mica	$1.5 \times 10^{8} – 9 \times 10^{12}$
Diamond	10^{12}
Semiconductors	
Wolframite	$10^{2} – 10^{5}$
Siderite	70
Hematite	$4 \times 10^{4} – 10^{7}$
Sphalerite	10^{5}
Conductors	
Pyrite	10^{-2}
Chalcopyrite	1.2×10^{-3}
Galena	10^{-3}
Magnetic iron pyrite	7×10^{-2}
Arsenopyrite	2×10^{-1}
Magnetite	6×10^{-3}

An example of metal sensor sorter so called ISS® - induction sorting system from the Company Steinert GmBH from Cologne/Germany is shown in Figure 1.1.3 [7].

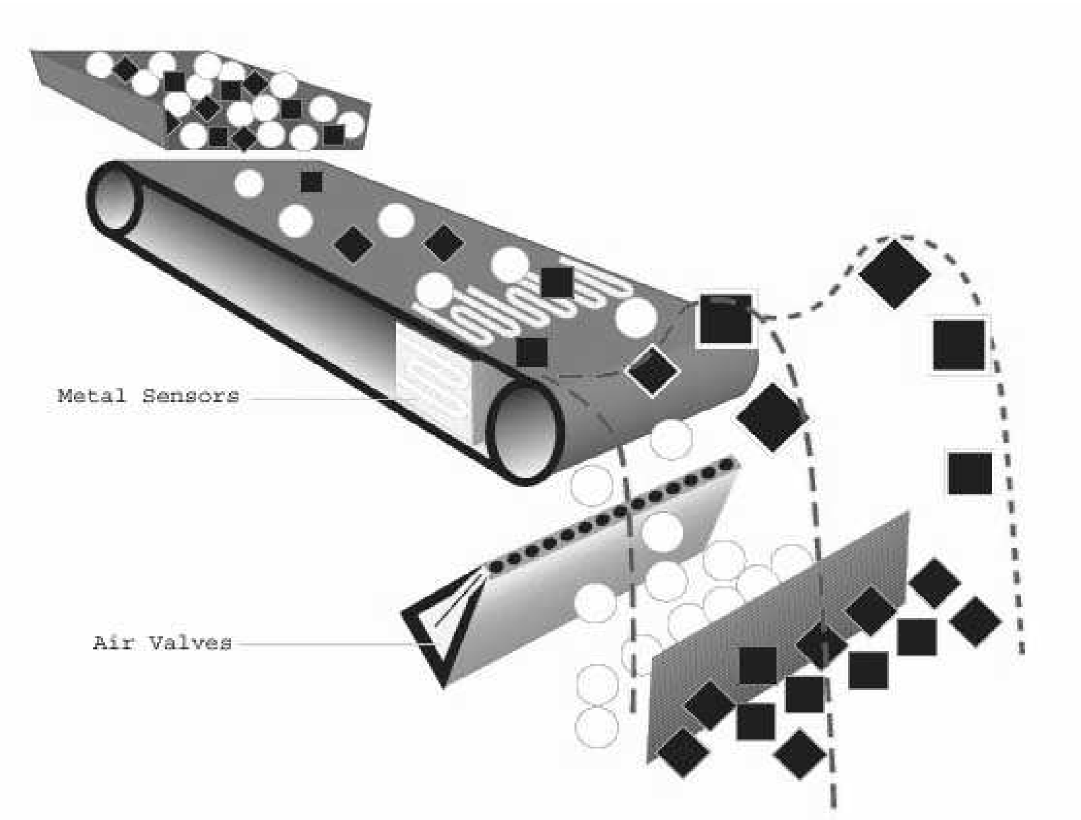


Figure Error! No text of specified style in document.**.3:** ISS®-Induction Sorting System from Steinert GmBH-Cologne/Germany [7]

4. 1.1.3. Radioactive Sensors

Detection of radioactivity is easy. But with the radioactivity sensors as radioactivity is a bulk property, it is not possible to gain the exact information of the material, e.g. size. Other sensors are needed to determine and identify relative consistence of the material or particle. Without any combination between size and the radioactivity of the ore there will be no efficient sorting process [3]. However, the application described above is only necessary for natural radioactive materials, neutron bombardment for most of the element produces radioactivity because of the isotope formation. As Sivamohan (1991) phased *"The detection is done using filters, to isolate specific wavelengths, and a pulse-height analyzer. The reverse of activation by neutron bombardment is the attack of a lump with γ-rays of specific energies in order to release neutrons".*

These kinds of sorters were applied to uranium ore which is a strong emitter of gamma-rays. This radioactivity can be easily detected by commercial NaI(Th) scintillation detector that is placed up to 25 mm above the rock surface. These machines are available for 25-50 mm and 50-150 mm feed sizes. An illustration of the machine is shown in Figure 1.4 [1].

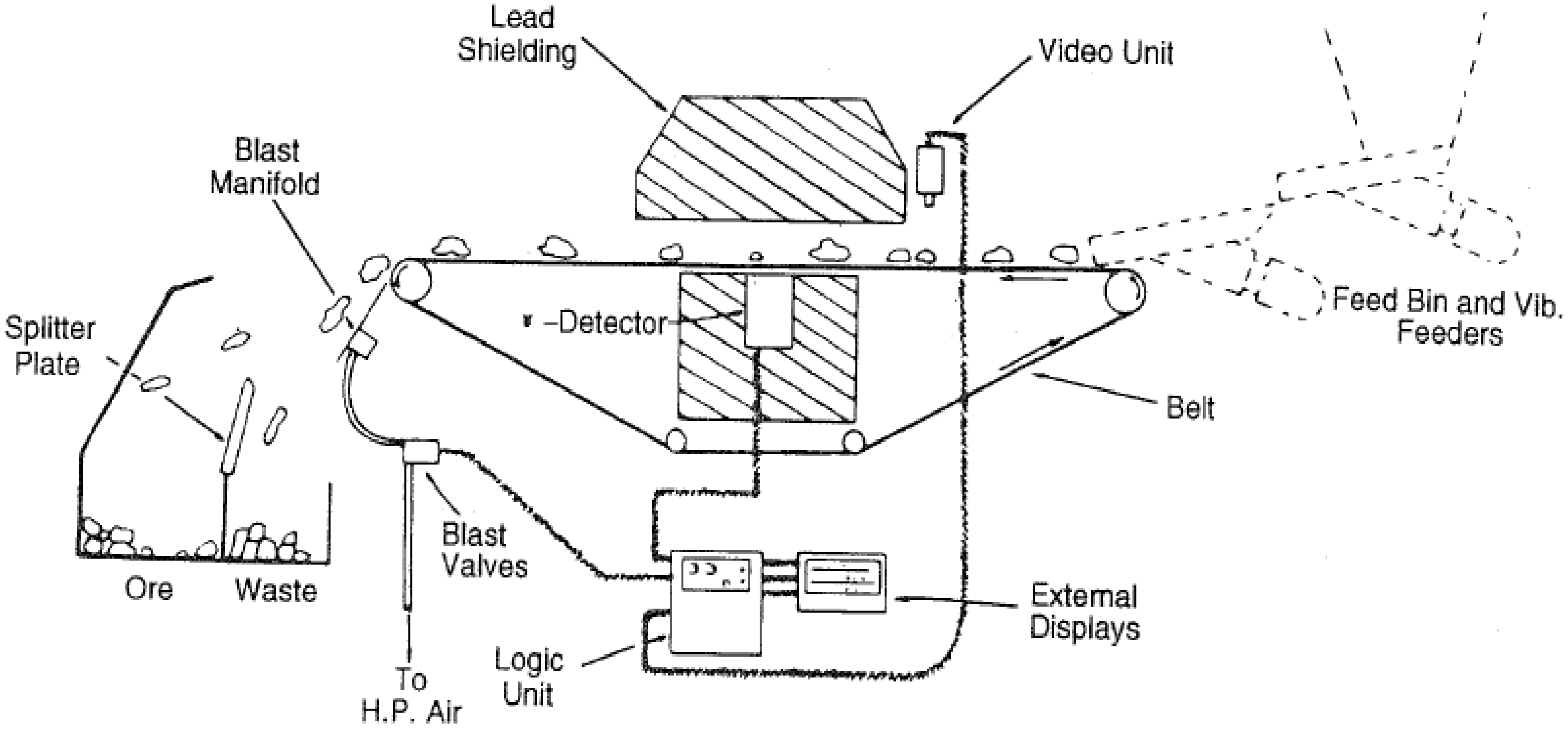


Figure Error! No text of specified style in document.**.4:** Radioactive sorting system based on gamma-ray emission [1]

5.

6. 1.1.4. X-Ray Sensors

Sorting with X-Ray depends on the penetrating capability of the minerals or particles, X-Rays usually penetrate to different depths of the minerals with different densities. Unfortunately this property of X-Ray can be used only on certain minerals like diamonds [3]. Minerals containing high atomic order absorb X-Rays more than minerals containing elements with low atomic order. As an identification; particles are projected to a two dimensional surface as shown in Figure 1.5 where a grayscale image is produced, differing locally and by intensity [4].

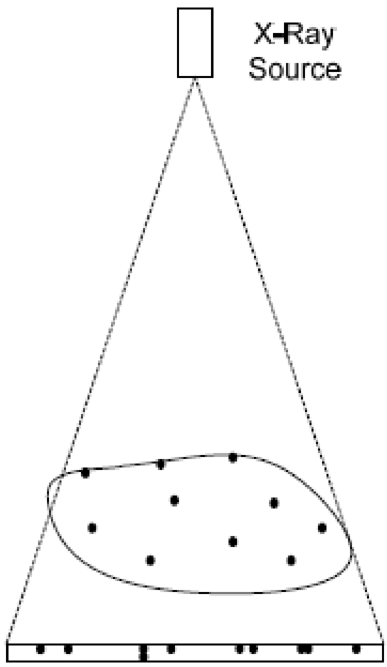


Figure Error! No text of specified style in document.**.5:** Schematic of X-Ray sensor [4]

The studies with this technology in the Delft University of Technology in Netherlands showed that a feasible pre-concentration between 5 and 50 mm is possible. An illustration in Figure 1.6 shows the principle of X-Ray sorting machine which is available in TU Delft [8].

X-Ray sorters can also be used in recycling industry. Figure 1.7 shows the application of an X-Ray sorter for detecting different particles, suitable for recycling industry.

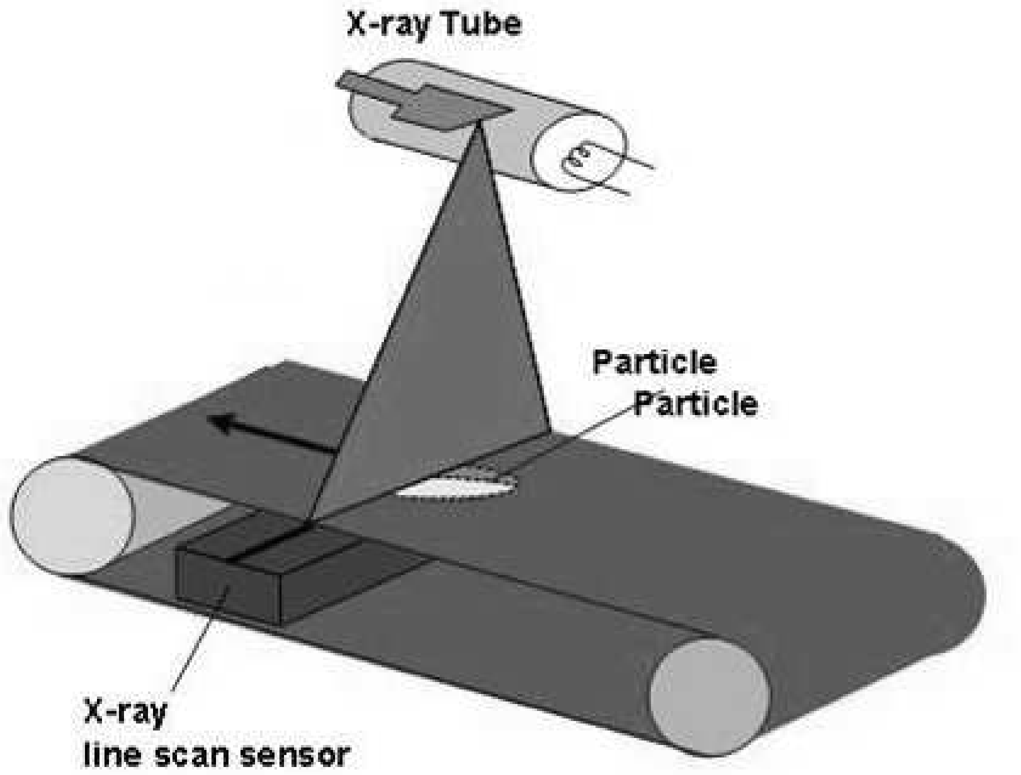


Figure Error! No text of specified style in document.**.6:** X-Ray Sorting Machine TU Delft [8]

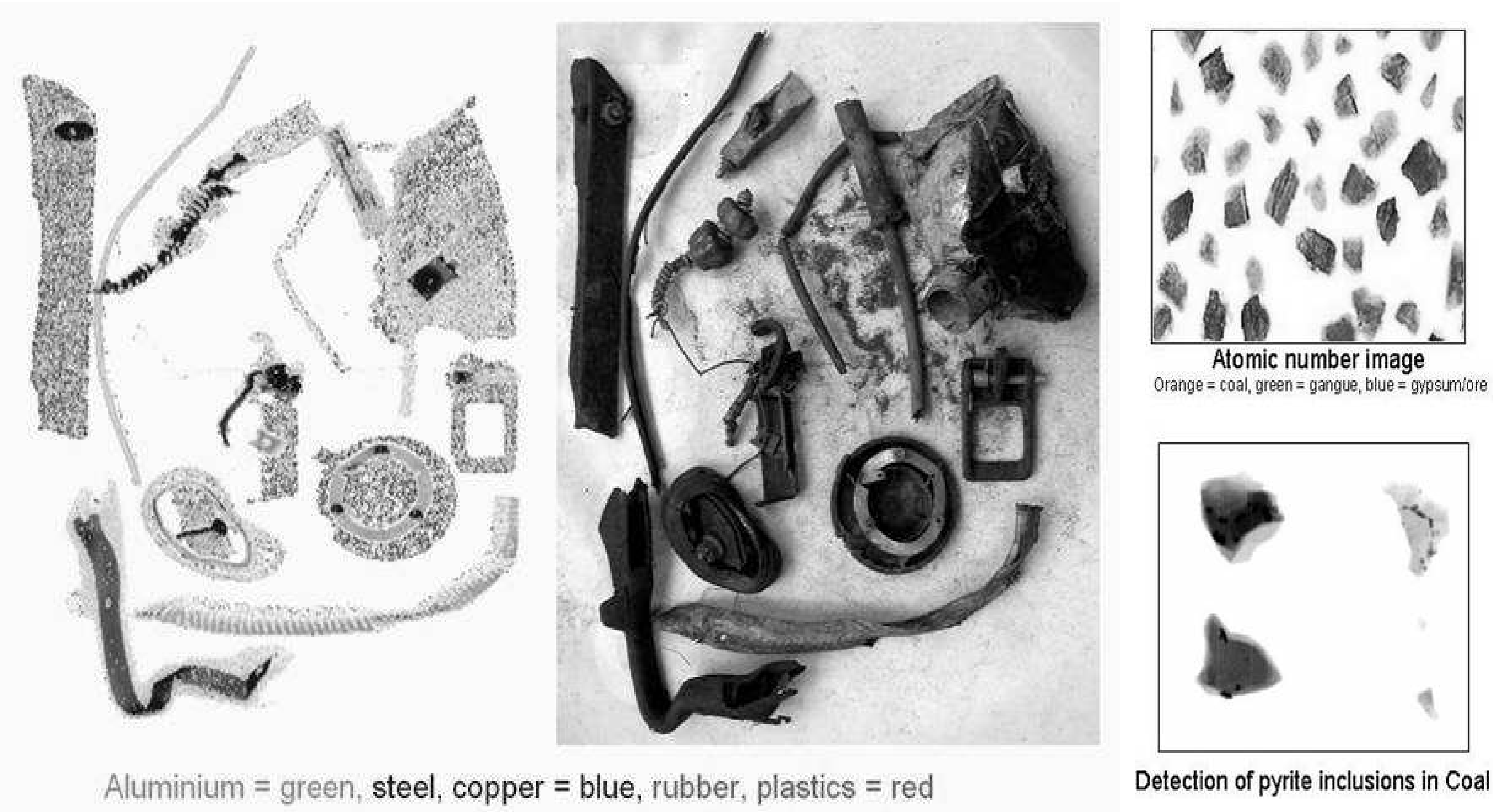


Figure Error! No text of specified style in document.**.7:** X-Ray views of various materials [8]

7. 1.1.5. Infrared Sensors

Infrared cameras are used to measure temperature of the materials. Even differences less than 1°K can be detected. Usually in the previous stage of heating especially by microwave, materials can be selectively sorted. Heating behaviors of some metals are shown in Table 1.2 [4].

Table Error! No text of specified style in document.**.2:** Heating behaviors of various minerals (1kW-2.45 GHz) [4]

Category	Mineral	Temperature (°C)	Time (min)
Moderately Heated			
Metal Powders	Al	577	6.00
	Co	697	3.00
	Cu	228	7.00
	Fe	768	7.00
	Mg	120	7.00
	Mo	660	4.00
Easily Heated			
Sulfide Semiconductors	FeS_2	1019	6.75
	PbS	956	7.00
	$CuFeS_2$	920	1.00
Mixed Valence Oxides	Fe_3O_4	1258	2.75
	CuO	1012	6.25
	Cu_2O_3	1290	3.00
	NiO	1305	6.25
Very Little Heated			
Alkali Halides	KCl	31	1.00
	KBr	46	0.25
	NaCl	83	7.00
	NaBr	40	4.00
	LiCl	35	0.50
Oxides	SiO_2	79	7.00
	Al_2O_3	78	4.50
	$KAlSi_3O_3$	67	7.00
	$CaCO_3$	74	4.25

There hasn't been commercial use of infrared sorters in mineral industry until today but some pilot and laboratory scale works have been carried out. Especially NIR (Near Infra Red) Sorters are commonly used for plastic sorting in recycling industry. Theoretically, NIR sensors work in the range of 0.7 µm up to 1.4 µm wavelengths but unfortunately this is just under 2 µm which is the necessary value for detection minerals [5]. A schematic diagram of a NIR-Sorter used in recycling field from the LLA Instruments GmbH-Germany is shown in Figure 1.8 [9].

8. 1.1.6. Optical Sensors for Fluorescence Excitation

Luminescence is a way of converting energy to light emissions [10]. When the luminescence suddenly occurs it is called "Fluorescence" [3]. In the popular science fluorescence is the material's light which can be recognized by human eyes. Fluorescence can be activated not only with visible light but also with a light beyond the visible light. With the developing technology, it is only a matter of time that the short-life fluorescence can be also detected and measured [11].

The minerals can generate fluorescence with UV-Light and also by X-Ray excitation, but as a matter of fact UV excitation is more economical and so on feasible [3]. The normal line-scan cameras are not sensitive enough to capture fluorescence, so the only way is using high sensitivity cameras. These kind of high-sensitivity cameras are able to produce just gray-scale images with today's technology, because of this reason a sorting by the fluorescing color is impossible at the moment [5].

The reason that generates fluorescence in minerals is the natural failures on the minerals geometry or structure: these commonly exist on the bonds with the trace elements or so called activators. The best activators are the rare earth elements, but unfortunately some of the elements defined as depressants, some examples are, iron, nickel and cobalt are counter to fluorescence and they usually make fluorescence weaker [14]. Table 1.3 shows the percentage of minerals in each mineral group that are known react excitation by UV light [5].

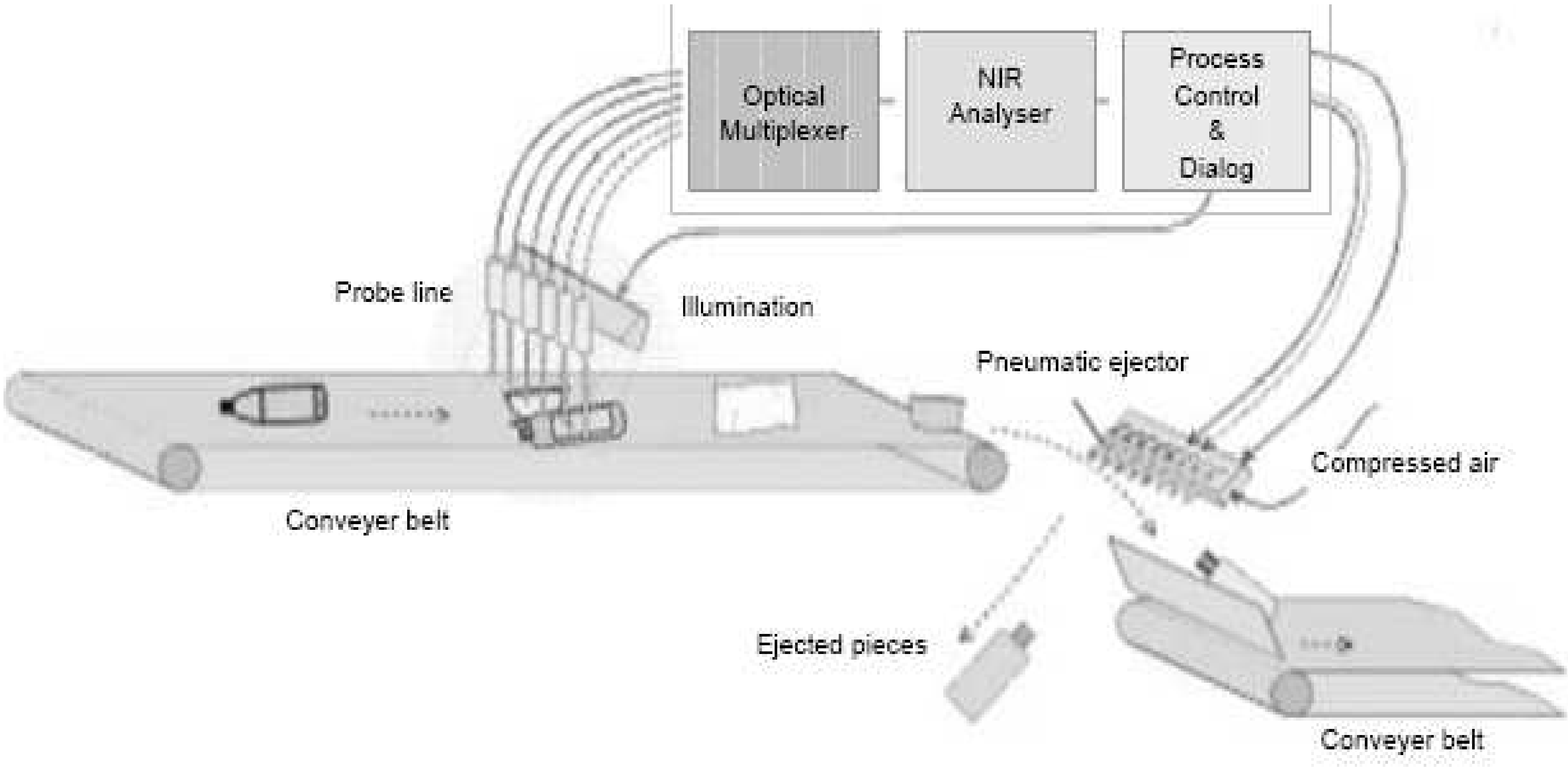


Figure Error! No text of specified style in document.**.8:** A schematic diagram of the equipment for sorting plastic parts [9]

Table Error! No text of specified style in document.**.3:** Percentage of known fluorescing minerals in each mineral group [5]

Mineral Groups	Percentage with Fluorescence
Sulfides	<1%
Sulfosalts	5%
Oxides/Hydroxides	0%
Halides	5%
Carbonates	15%
Borates	30%
Sulfates	30%
Phosphates/Arsenates	10%
Tungstates	10%
Silicates	15%
Sulfides	20%

The fluorescence luminescence measuring efficiency and sensitivity of a material depends on the following parameters [3]:

- wavelength of excitation
- excitation energy
- quantum yield of the material
- wavelength of adsorption
- time of the measurement after the excitations end

In Table 1.4, some examples of fluorescence minerals under day light and UV-light are shown [12].

Table 1.5 shows some fluorescent mineral prospects when excited by UV [3].

Table 1.4: Various fluorescent minerals under day and UV lights [12]

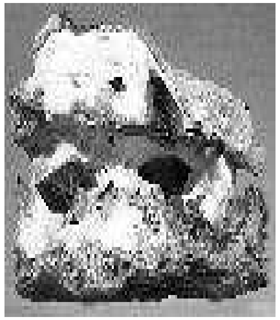
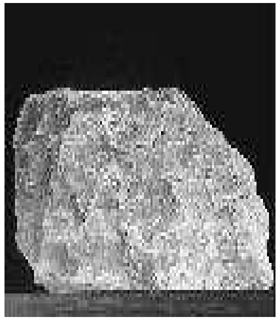
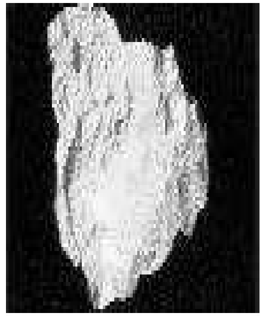
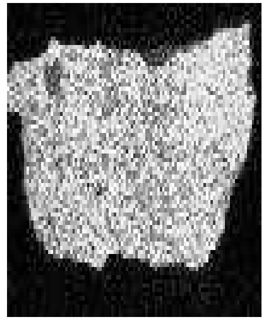
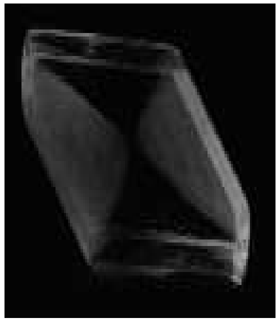
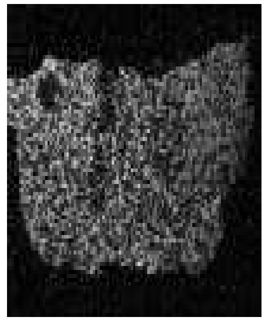
Daylight					
UV					
	Benitoit	Gypsum	Scapolite	Tyuyamunite	Zippeite

Table Error! No text of specified style in document.**.5:** Fluorescent Mineral Prospects when Excited by UV [3]

Mineral	Composition	Ultraviolet Range		Probable Color of Fluorescence
		Near	Far	
		4-300mμ	3-200mμ	
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				
-Calcedony	SiO_2	x		Yellow-green
-Opal	SiO_2	x		Yellow-green
-Agate	SiO_2	x		Yellow-green
Spinell	$MgAl_2O_4Cr$	x		Red
Kyanite				
-Disthene	Al_2SiO_5Cr	x		Red
Corundum				
-Saphire	Al_2O_3Ti	x		Orange-red
-Ruby	Al_2O_3Cr	x		Red
Beryl	$Be_3Al_2(SiO_3)_6Cr$	x		Red
Autunite	$Ca(UO_2)_2P_2O_8.8HO_2$	x		Greenish-yellow
torbernite	$Cu(UO_2)_2P_2O_8.12HO_2$	x		Greenish-yellow

9. 1.1.7. LIBS (Laser Induced Breakdown Spectroscopy)

A focused pulsed laser on a single spot on surface produces plasma. Basically the emitted photons from the plasma are measured by a spectrometer which could be calibrated to identify specific spectral lines occur in the LIBS system. LIBS system is already in use for quality control of the feed on the belt conveyor. But to apply this system in order to measure a single particle on a moving belt, the detection of the particle can be done with an optical line scan camera. Until today the LIBS technology was applied only for aluminum alloy sorting, which was on pilot scale sorter. A direct online analysis on a particle surface would be a big revolution for mineral processing industry [5].

Because of the relatively smaller surfaces identified by laser pulse and the scanning frequency, the analysis of homogenous particles can be done efficiently, but for typical disordered ores like sulphides, the measurement is depended on the spot that the laser beam hits. Some improvements like splitting on the laser beam into several sub-beams are applied, but the problem would basically remain, regarding to the fact that it is necessary to combine LIBS system with other sensors like LIF [5].

10. 1.1.8. LIF (Laser Induced Fluorescence)

The main principle of LIF is to excite the fluorescence as a light source using a laser instead of UV light. By using the special characteristic of laser, the adsorbed amount of the reflected laser can be measured [14]. .

LIF analyzers can analyze the bulk streams online. Basically an ultraviolet laser excites fluorescence on a particle surface and measures this occurrence time with resolution less than 1 nanosecond (ns) using spectrometers or photomultipliers [5].

The lifetime of fluorescence is defined as, when the luminosity of fluorescence dropped from 100% down to approximately 37%. For minerals this lifetime can be really short, for example apatite has a lifetime of 60 ns which is very short when compared with the other light sources. Despite the short lifetime, the mineral type can be identified with necessary detectors [14].

There is a possibility to widen the laser beam diameters up to 80 mm and will still produce enough energy to excite fluorescence. With the LIF technology it is even possible to excite fluorescence with the minerals which are not fluorescence with standard UV lamps [5].

The measured signal should be identified and matched with the mineral types for each deposit. The fluorescence depends on activating elements with regular fluorescence that is already visible with UV lamps [5].

11. 1.1.9. Combination of Sensors

Sometimes for optimal results, application of more sensors in sorting can be more effective. When one sensor detects a particle, based on one characteristic, another one can be used either to control the identification or to use another characteristic measurement to make the sorting with less failure.

But in order to accomplish this kind of sensor combinations there are things to be considered. Different sensors have different properties or need different inputs [5] such as:

- resolutions
- acquisition times
- scanning velocities
- scanning widths
- different lightening
- background
- feed conditions
- analogue outputs
- digital outputs
- velocity

Using one sensor is an advanced technology in computer algorithms for data processing and filtering. For using sensor combinations because of the sensor calibration, adjustment, coordination, integration and data processing even higher technology is necessary.

Nowadays sorters can use a combination of 2 high-resolution and 1 low resolution sensors in “near-real-time” velocity. But there is a big further way and potential in “multi-sensing-technology”. The common example of multi sensor technology of today’s sorters world, which is already a state of art in the recycling industry, is a combination of metal detector and optical cameras for metal sorting.

12. 1.2. Applications, Benefits and Drawbacks of Sensor Sorting Technology

13. 1.2.1. Applications of Sorters

As already discussed, electronic sorters are being used commonly in the food industry. The working principle is almost the same in most cases; as shown in Figure 9 [13].

The shapes of the materials’ fractions are almost the same so for a successful application an easy adjustment would be enough, for example sorting depending on brightness. Because of even size distribution of fruit fractions rejection and positioning would not be a problem at all. The application of color sorting system in various fruits and vegetables sorting industry is shown in Figure 1.10 [14].

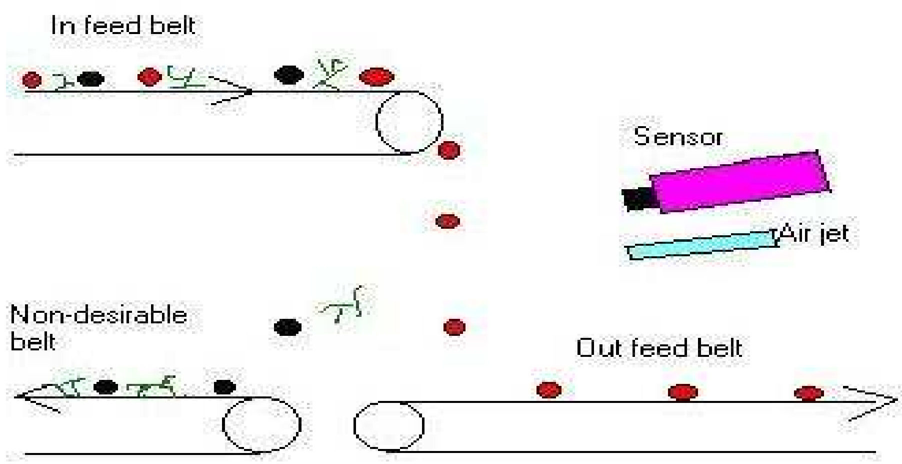


Figure Error! No text of specified style in document.**.9:** Electronic sorting of fruits [13]

Figure Error! No text of specified style in document.**.10:** Compac™ Color Sorting System-InVision 5000 [14]

A sub industry of mineral processing and recycling, is one of the industries that the sorters have a big application area. Sorters are a "state of art" in most of the recycling plants, for example, optical sorters in glass and paper recycling, inductive sensors in metal recycling and NIR Sensors in plastic recycling [5]. An example of electronic scrap sorting is shown in Figure 1.11 [15].

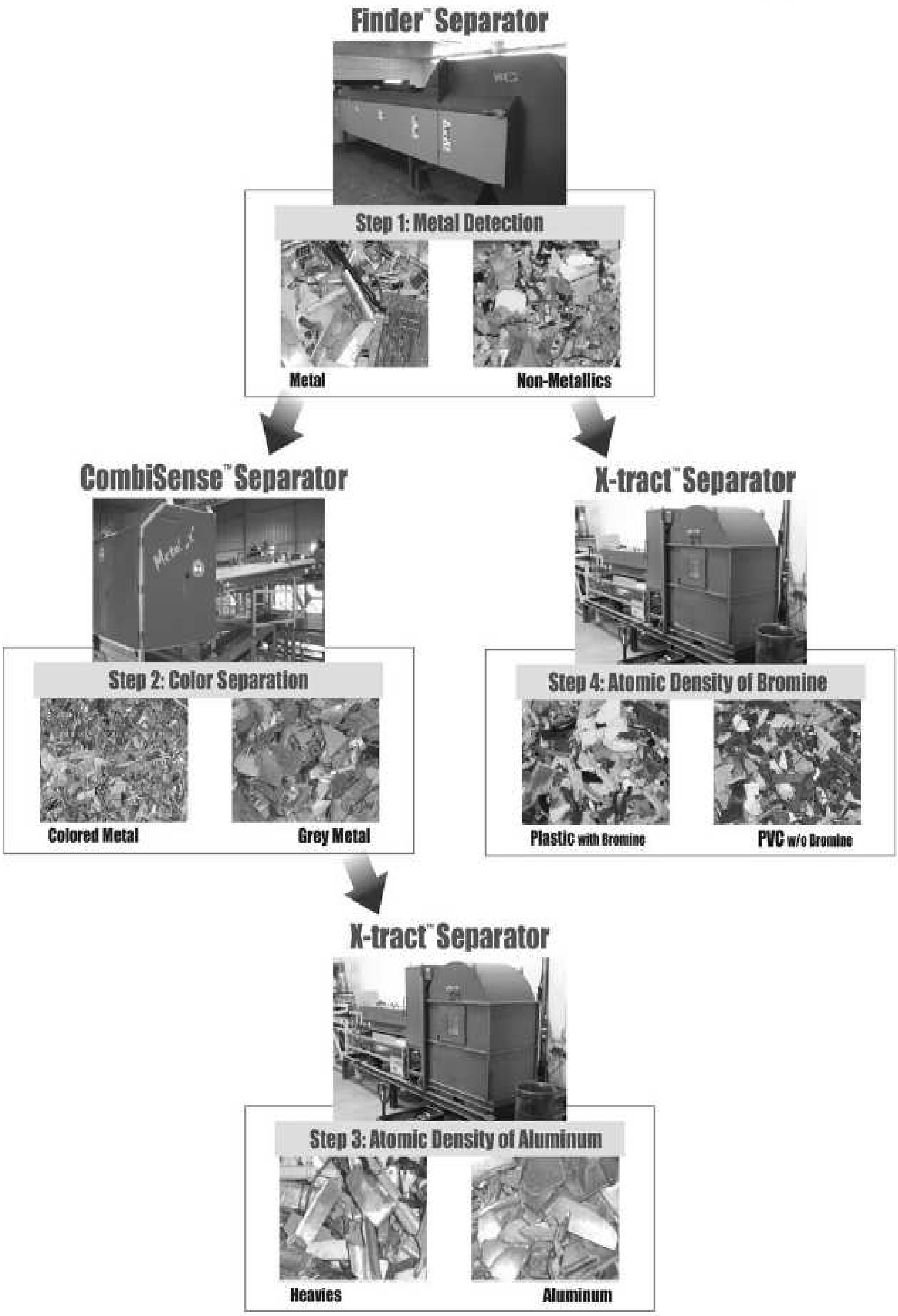


Figure Error! No text of specified style in document.**.11:** Electronic Scrap sorting [15]

Sorting is one of the developing processes for mineral processing plants. Electronic sorters can be installed basically for the following duties [5]:

- pre-concentration of the plant feed
- intermediate product production
- finished product production

Electronic sorting enlarge in more and more potential application areas but the known sorter pre-concentration applications are shown in Table 1.6 [2].

Table Error! No text of specified style in document.**.4:** Application of sorters [2]

Discrimination Technique	Minerals sorted
Photometric (optical)	Uranium, uranium/gold, coal, limestone, magnesite, base-metal sulphides, wolframite, phosphates, talc, spodumene, lignite, feldspar, wollastonite
Radiometric	Uranium and uranium/gold
Conductivity/magnetism	Copper sulphides
UV fluorescence	Scheelite, limestone, shale
Microwave attenuation	Kimberlite (prototype)
Gamma scatter	Base metal sulphides
X-Ray luminescence	Diamonds
Note: various combinations of discrimination techniques have been used in some machines.	

One example for application of sorters in a mineral processing plant is a limestone mine (Nordkalk Company) in Finland. The machine shown in Figure 1.12, is used for sorting of 500 t/h dolomite and calcite.

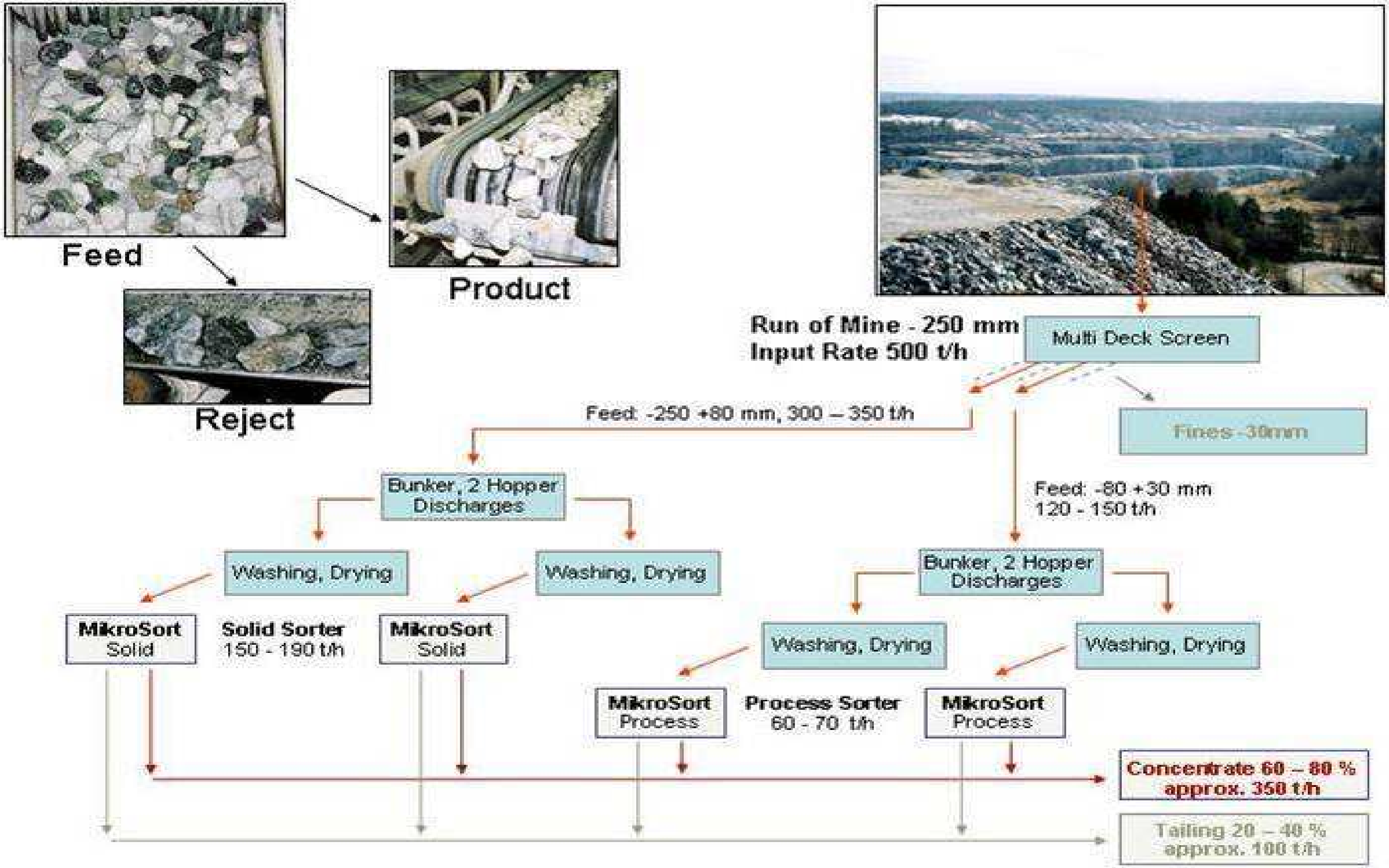


Figure Error! No text of specified style in document.**.12:** Limestone color sorting dolomite/calcite at NORDKALK, Finland [8]

The ranges of available optical sorters classified by the Technology University of Delft, Netherlands for minerals sorting are shown in Figure 1.13 [8].

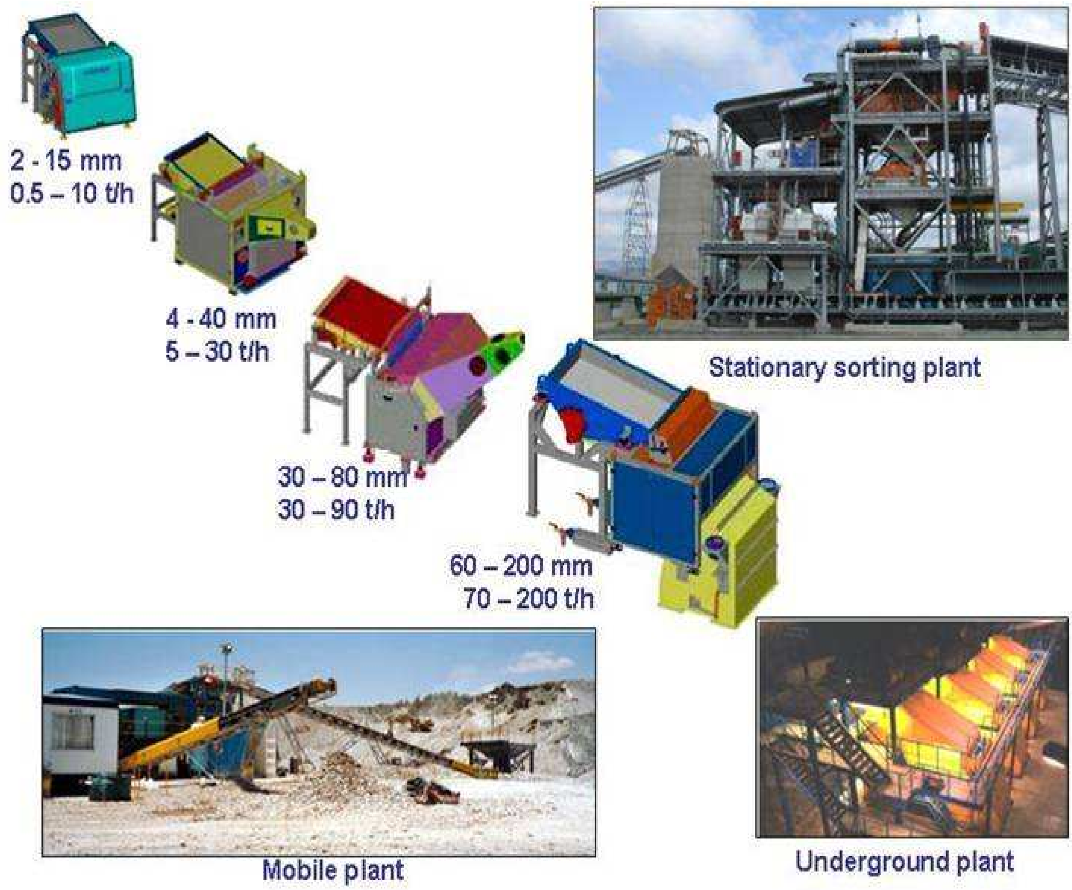


Figure Error! No text of specified style in document.**.13:** Range of optical sorters for minerals and typical applications [8]

1.2.2. Benefits and Drawbacks of Sensor Based Sorting in the Minerals Industry

The most important possible benefit of all machineries used in mineral processing plants to improve processing and product quality, is to profit, so it's with the electronic sorters. If a sorter produces a final product which is not possible with the other machinery, like magnesite sorting in Greece, the benefit is significant. The common duty for sorters is pre-concentration, although the advantages are numerous, these would not be unique because most of the pre-concentration methods are offering similar advantages [2]. The benefits of pre-concentration can be summarized in the following statements [5]:

- less overall capital costs
- less operation costs
- less disposal costs

- less environmental impact
- optimal process recovery
- increasing in the production-if applied in an existing plant
- increasing the reserve life by reduced cut-off grade
- profiting from the mines which used to be unfeasible
- allowing application of high-productive but less selective extraction methods
- transportation of pre-concentrated material to the main mineral processing plant
- leaving the coarse waste if applied in or near the extraction area, especially refill type underground operations

One another important advantage of electronic sorters is energy saving. For example energy consumption for using a sorter with an air valve ejector is around 1-3 kWh/t. It is noted that this range is related to the size of the particles. This amount compared to the energy needed for grinding the particles to flotation size, which is about 12-15 kWh/t, is remarkable. Unfortunately talking only about energy savings can not be the point, if the materials are not crushed over coarser sizes [5].

The disadvantages of a pre-concentration step are [3]:

- the cost of a pre-concentration plant
- the cost of sizing the feed of for the pre-concentrator
- the cost of washing and drying the feed to the pre-concentration plant
- loss of valuable minerals in the pre-concentration step
- non applicability to the diffused ore types

Depending on the type of sensors, some other mistakes and problems can also happen. In optical sorting, one of the most common problems is the side that the particle lays. Each particle can lay on one side. In this position the upper face will be scanned, but the other side which is on the band can not be detected and it can be that these two sides have different colors or different characteristic. This problem is shown in Figure 1.14 on colemanite minerals.

For an optimal sorting the particles on the feed belt should be singled. Any coupled particles can be identified as a single particle and depending on the definition on the computers cache it brings some losses in waste or in the concentrate.

Figure Error! No text of specified style in document.**.14:** Two different sides of the same mineral

Dust is a routine problem in mineral processing. It is more or less a part of every process from extraction to final product. Dust can affect especially optical sorters but also the lightening for the camera sight. For this reason, a wiper or washer can be necessary for the cameras. Because of existing dust, the surface of the samples, here particles can become dirt and this can have a bad effect on the sorting process. Although the solution is washing the samples, this is not that easy in the areas with water problem.

Some health and safety problems occur when the UV lights or X-Ray sensors are installed in the sensor. For this reason a durable housing and more safety for the operator can be necessary.

Optical sorters are calibrated by the producer for the main material of the plant. The sample colors are installed in a range of definition. Although the possible dilatation is made by the programmer before the installation of the sorter to the plant, any extreme changes in the color, especially in the ejected material can cause disruption in the whole process. In this kind of situation their service is necessary for the sorter.

Final production sorters have some limits such as size. With latest technology sorters can work till down to 1 mm feed size, unfortunately for an optimal sorting a minimum particle size should be around 10-20 mm. On the other side the maximum feed size for electronic sorter is around 300 mm.

Any damage in the sensors can cause high costs in maintenance. For heavy duty operations special designed sorters can be necessary. As a matter of fact there must be some serious calculations before installing a sorter to a plant because the electronic sorters are more expensive when compared to other equipments eventually in the first investment.

14. DEFINITIONS OF THE MATERIALS

2.1. Scheelite

2.1.1. Geology and Mineralogy of Scheelite

Scheelite is a calcium Tungstate. Its chemical formula is $CaWO_4$, with 19.45 CaO and 80.55 WO_3, its hardness is 4.5-5. Special density of 5.9-6.2 and it is "Tetragonal" in shape. Reaction with hydrochloric acid performs a yellow WO_3 solution, which turns into stannous-blue in color by heating. The sodium phosphate bead in the reduction flame turns into green or yellow when it is hot and in cold temperatures changes to blue [16]

Scheelite is usually occurred as a metamorphose product within Wolframite. Mostly scheelite is formed in a less amount in the wolframite reserves. The most important scheelite deposit is in California-San Bernardino Country [16]

Scheelite, when it is pure, reflects brilliant blue-white with the short wave ultraviolet lamp, with characteristic gemlike sparkle. Associates color the reflection to whitish, cream, yellow or slightly orange [17]. Scheelite under daylight and UV light is shown in Figure 2.1 [12].

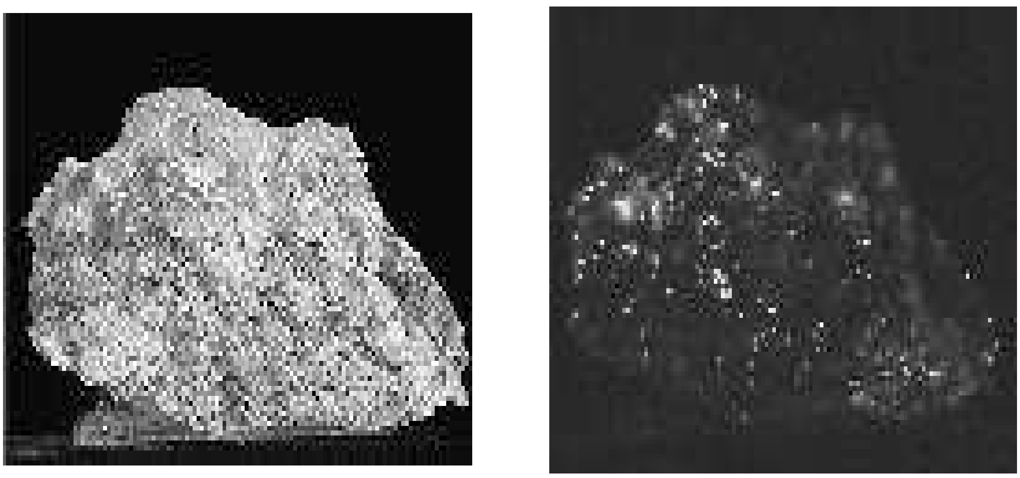


Figure Error! No text of specified style in document.**.15:** Scheelite under UV and daylight [12]

Scheelite would not fluorescence at wavelengths longer then 3000 angstrom, so it won't response to black-light lamps or long-wave tubes. If the reflection remains after the light is turned off, the reasons can be because if a thin coating of something else, like calcite or hyalite opal. With its well defined sharp edges, the reflection does not fade into rock matrix [17].

2.1.2. Application and Usage of Scheelite

Scheelite is used as a second source for wolfram after wolframite. Wolfram is one of the heaviest mineral with the density of 19.3 g/cm^3. Its extremely high melting point which is 3410°C and its stability, define it as a strategic mineral in our century. It is used to produce friction-resist metal in the form of wolfram carbide also for alloy metals used in high temperatures. With its high electric conductivity it has been used in the electronic industry. Wolfram is one of the minerals used in production of electrodes, switches and lamps [18]. The world's wolframite production 2003 is shown in Figure 2.2 [19].

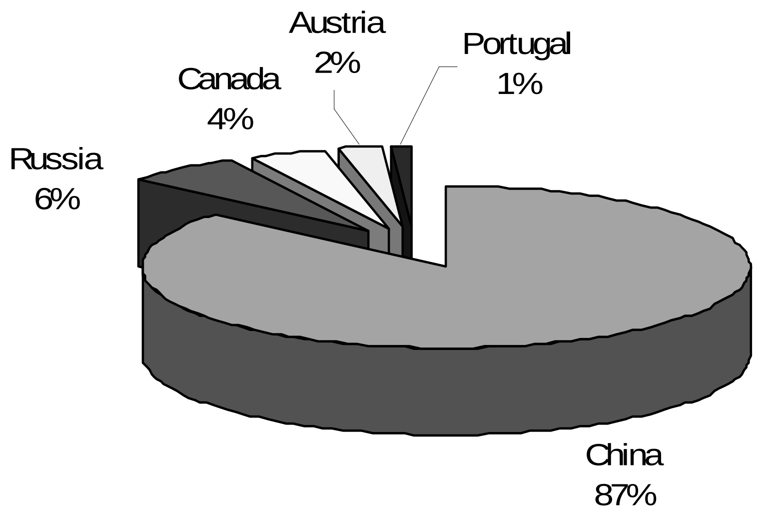


Figure Error! No text of specified style in document.**.16:** Wolframite production 2003 [19]

2.1.3. Scheelite Processing

Today's one of the biggest still in process scheelite processing plant is Mittersil in Austria. The plant is working with a capacity of 260,000 t/y and with a mean 0.7% WO_3 content in the feed material. In the plant the rough concentrate contains 30% WO_3 and the finished product contains about %65 WO_3.The flow-sheet of the Mittersil Plant is shown in Figure 2.3 [20].

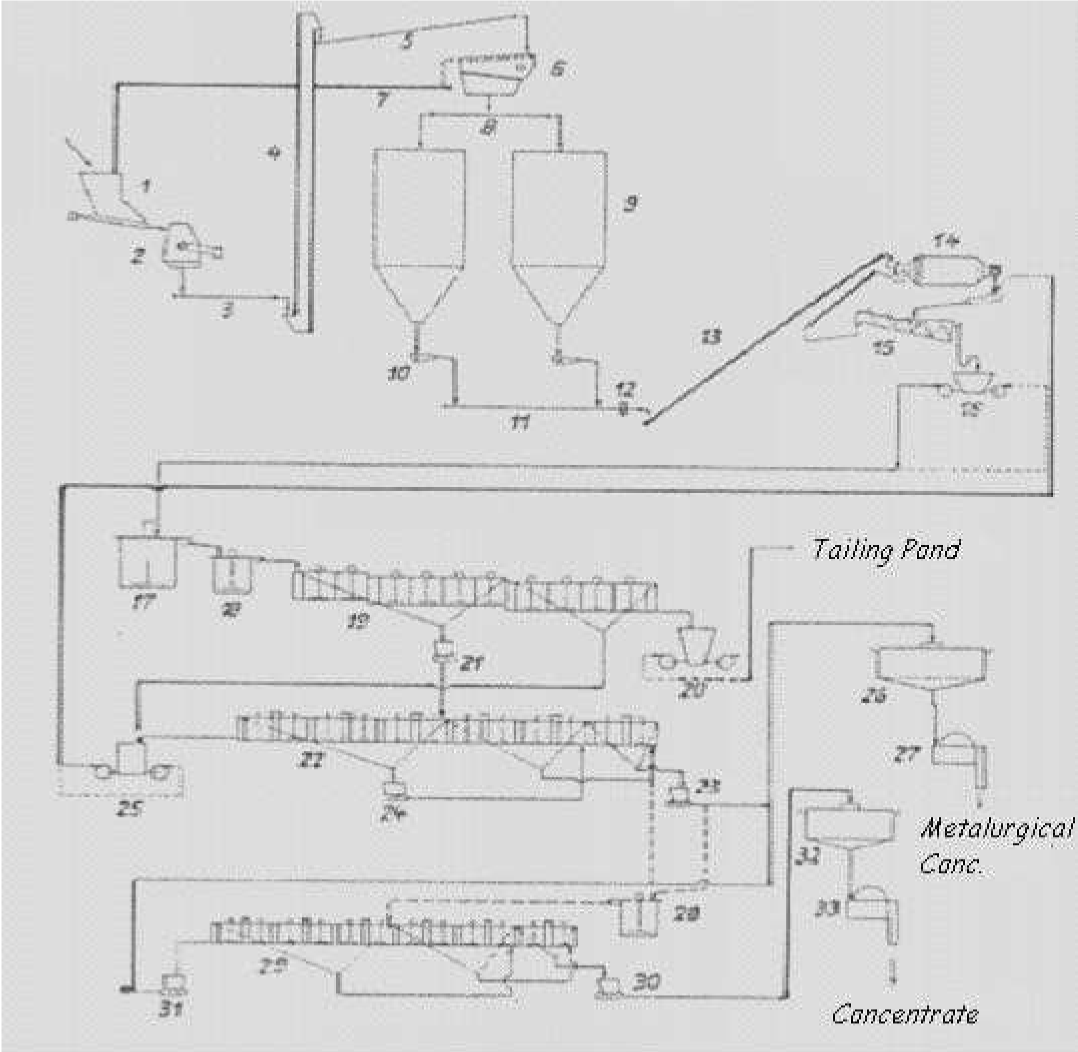


Figure Error! No text of specified style in document**..17:** Scheelite Processing in Mittersil, Austria [20]

In the Mittersil Plant the milling process starts with an impact crusher (1470 mm wide, 4 m long) followed by a ball mill (550 KW). After milling the scheelite particles contained in the quartz stones at about 80 µm, they are liberated and ready for the flotation. The pulp is hot-conditioned with sodium hydroxide and sodium silicate as pusher about at 60°C. The necessary flotation pH is about 10.8. For collector reagents tall oil and flotinor S72 are used [20].

A process depending on the gravity properties of scheelite was constructed in Uludag, Turkey. It was planned to operate 1000 t/d but the operating capacity hanged about 500-600 t/d feed. A brief work about the plant is as followed: the run of mine (ROM) ore is introduced to a jaw crusher and then a cone crusher to be crushed under 20 mm. The crushed material is fed to a rod mill to obtain a fraction under 1 mm. A hydrosizer with 6 different size fractions maintains desliming. The coarser fractions fed to 3 step shaking tables, followed by shaking table and flotation. By shaking table and flotation the pyrite minerals disposed with the tailings. After this step the concentrate is introduced to wet magnetic separation so that the magnetite from the scheelite can be separated and a concentrate with the 65% WO_3 gained. The block-diagram flowsheet of the facility is shown in Figure 2.4 [18].

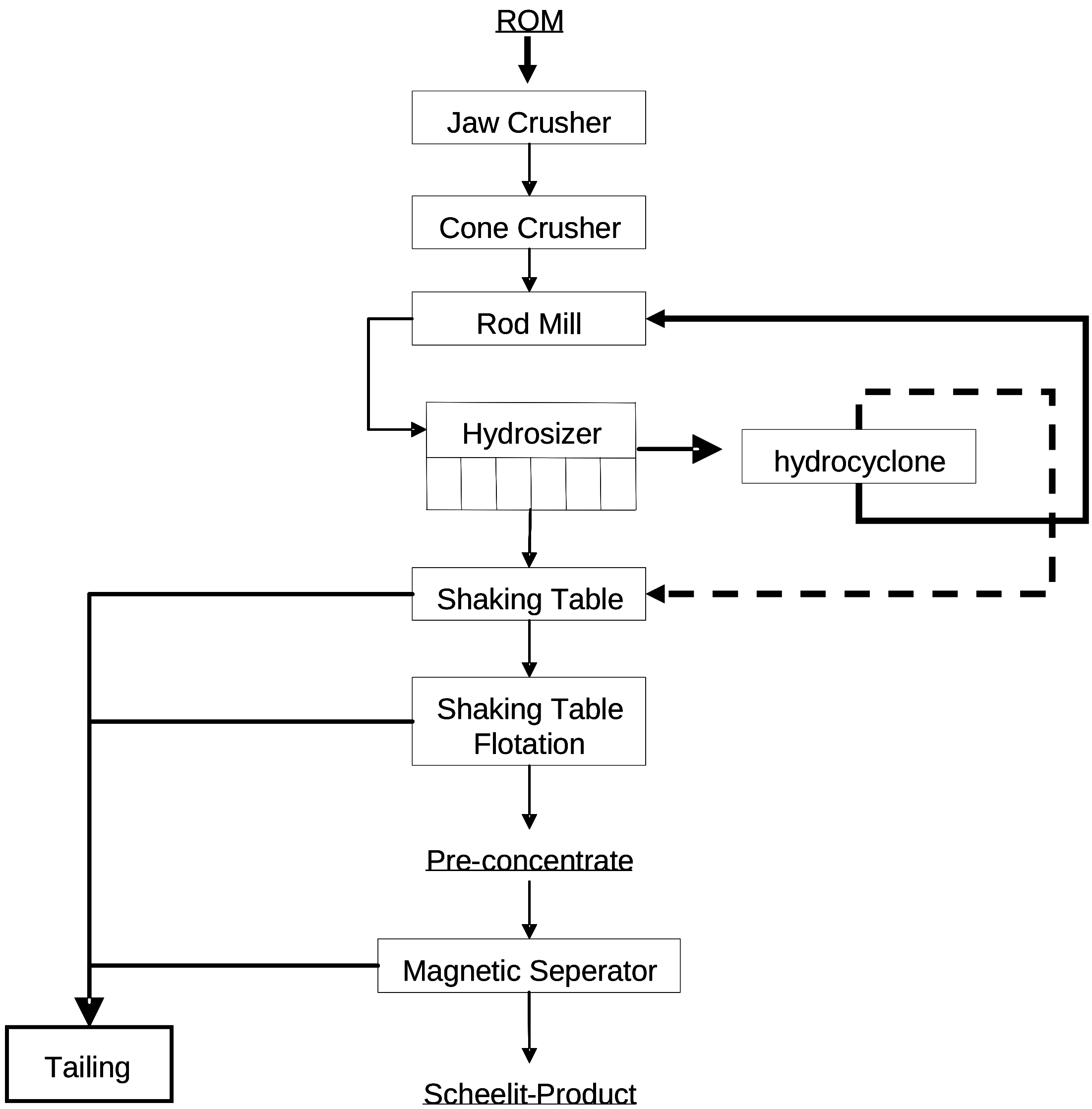


Figure Error! No text of specified style in document.**.18:** A simple flowsheet of the Uludag Scheelite-Plant [18]

2.2. Fluorite

2.2.1. Geology and Mineralogy of Fluorite

The fluorite also called as fluorspar is shown with the chemical formula of CaF_2 containing 51.1% Ca and 48.9% F. The specific gravity of fluorite is 3.18, the hardness is 4 (Mohrs Scale). It crystallizes in isometric system with a perfect octahedral cleavage. It forms foam with the dilute hydrochloric acid. When it is heated with the sulphuric acid, it starts to vapor hydrofluoric acid, which can melt glass [21]

Fluorite is rarely contaminated with impurities but mostly associated with gang minerals. Therefore, it has to be separated from gang minerals a commercial use. Fluorite is a glass like mineral, mostly between transparent and semi transparent. It can be clear and colorless. It also occurs in a range of colors like violet, lily, purple, green and yellow [21].

Fluorite is mostly occurred in veins and in sedimentary formations. It can also be found as minor quantities in granite, syenite, pegmatite, gneiss, schist, rarely in volcanic rocks. Calcite, barite, quartz, galena and sphalerite are the most common minerals associated with fluorite [21].

Fluorite occurs in every continent. The countries produce fluorite, for commercial usage are: The United States of America, Canada, Newfoundland, Mexico, Guatemala, Brazil, Bolivia, Argentina, England, Scotland, France, Germany, Spain, Italy, Switzerland, Norway, Russia, China, Israel, South Africa, and Wales, Australia [21]. The leading countries in fluorite production in the year 2005 are shown in the chart in Figure 2.5 [19].

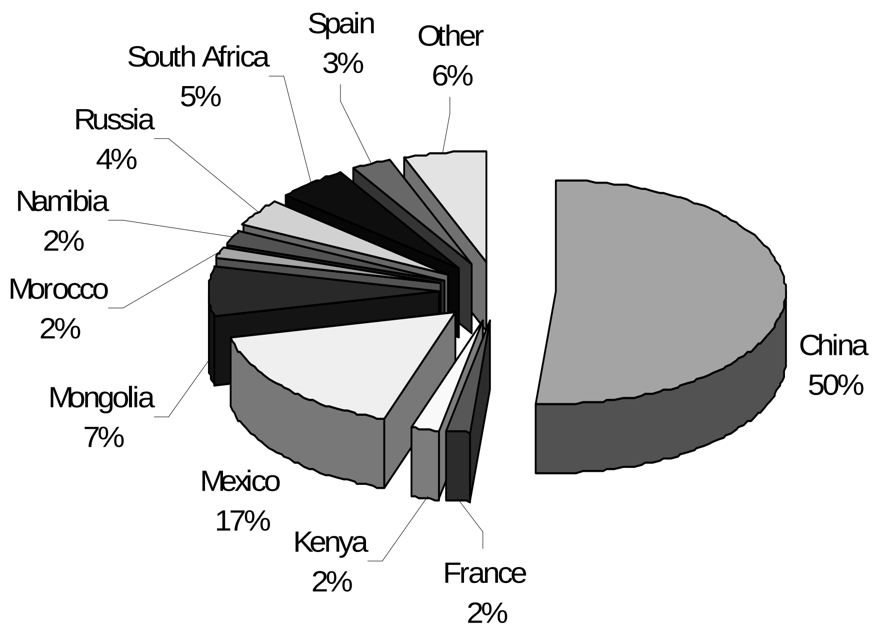


Figure Error! No text of specified style in document**.5:** World fluorite production 2005 [19]

Although fluorite's fluorescence is often blue, sometimes it is brown under daylight and fluorescence is yellowish to cream. When it fluorescence as green, white or brownish it can be better to use a long wave light. Sometimes it is also phosphorescent; usually thermoluminescent, it glows when it is heated [17]. In Figure 2.6 the different excitation of fluorite under day and UV light is shown [12].

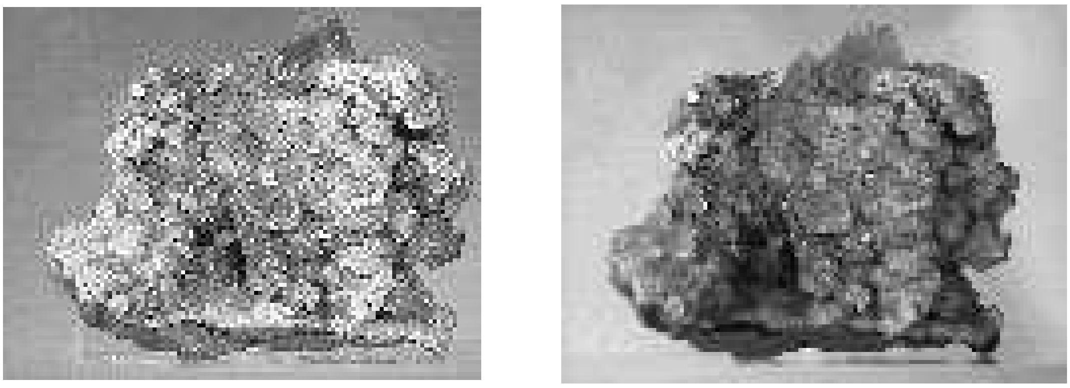


Figure Error! No text of specified style in document.**.6:** Fluorite under day and UV light [12]

2.2.2. Application and Usage of Fluorite

The most common application of fluorite is in the chemical industry for producing hydrofluoric acid. The other common usages are aluminum, steel, ceramic, enamel, glass and cement industries [22]. It is also used for galvanization, plastic production, uranium enrichment, etc. In iron smelting plants, fluorite is used as a flux. It is also used for special optical lenses. Fluorite is a rare gemstone and is one of the most popular mineral for mineral collectors, actually the second one after quartz [12].

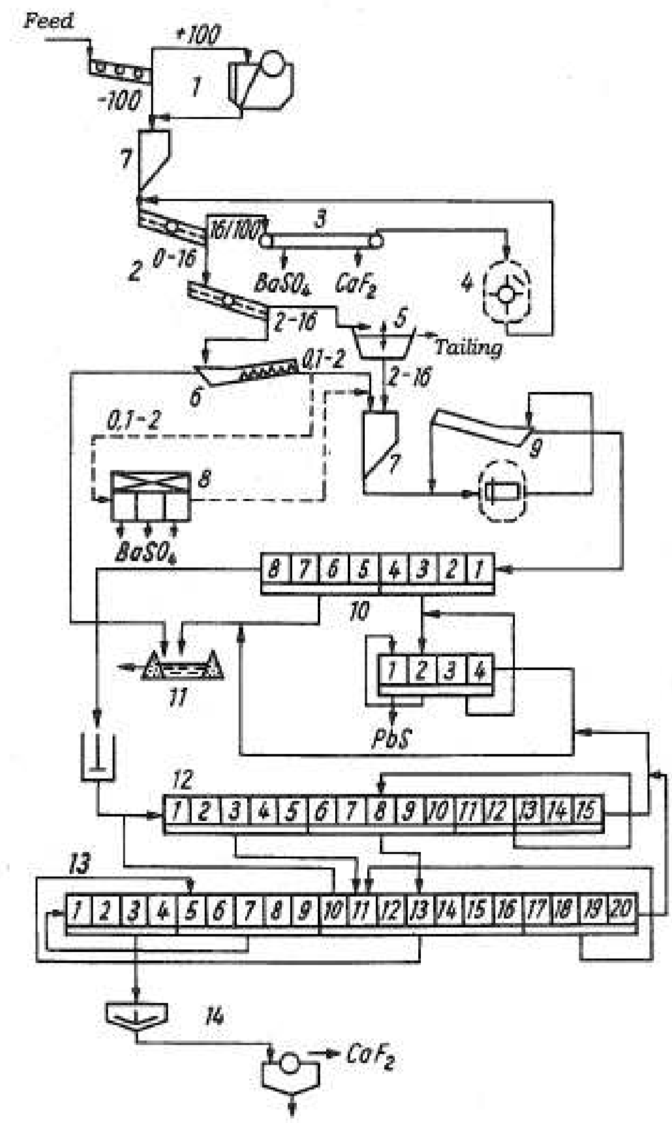
2.2.3. Fluorite Processing

The oldest and simplest method for the enrichment is hand sorting combined with washing to have pre classified feed on band or tables. The rest of the processes are mostly comminution steps and classifying steps [22].

Jigs are commonly used for the material between; 3-25 mm. The middlings of this step is mostly sent to another step of milling and followed by a fine processing. Because of the big density difference (0.1-0.3 g/m^3) a large fraction of material (1-200 mm) are enriched via HMS (Heavy Media Separation) [22].

The ores containing around 10% CaF_2 or so called "poor reserves" are more necessary for flotation. Due to fluorite's different Zeta-Potential which is +69mV compared to its gang materials, Barite with -45 mV and Quartz with -82mV; a flotation with alkyl sulfate or alkyl sulfonate would be enough for a successful enrichment [22].

The flotation products are mixed with the necessary binding material (petrochemistry wastes, cellulose wastes, calcium hydroxide, clay, bauxite, etc.) in a rotating drum for producing pellets or briquettes. An example of fluorite processing plant is shown in Figure 2.7 [22].



1. Crusher
2. Vibration Screen
3. Hand Sorting
4. Impact Crusher
5. HMS
6. Screw Classifier
7. Middle Silo
8. Piston Jig (0.2-1mm and 1/2mm)
9. Ball Mill and Classifier
10. Sulfide-Flotation
11. Water Clearer
12. Fluorite 1. Flotation
13. Fluorite Cleaning Flotation
14. Thickener with Drum Filter

Figure Error! No text of specified style in document.**.19:** An example flow sheet of fluorite processing [22]

3. EXPERIMENTS

3.1. Aim of the Study

The aim of this study is to find a sensor which makes possible to sort two different minerals, namely fluorite and scheelite which belong to fluorescent minerals, by applying new sorting methods with the use of their different properties. For this reason the newest multi sensor sorter which exists and is situated in the mineral processing department (AMR) of the Technology University of Aachen (RWTH-Aachen) was used.

This machine is able to sort particles based on the color, brightness and transparency (line scan color camera), fluorescence (UV camera), electrical conductivity (metal sensors), dimension (3D camera) and heating conductivity (infrared camera). For fluorite and scheelite, the efficiency of these sorters were studied and when necessary, the combination of two or more sensors' effect on the sorting are also investigated.

3.2. Machine Description

MIDAS (Multi Detector Array Sorter) situated in the department of Mineral Processing (AMR) of the RWTH Aachen University, is used in the experiments. MIDAS made by the company CommoDaS^{R} under direct idea and order of AMR shown in Figure 3.1 is a special designed electronic sorter with different sensor types which are suitable for research and pilot scale works.

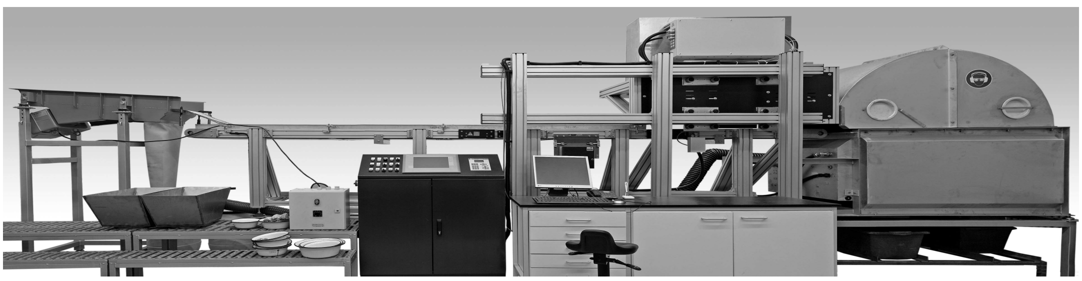


Figure Error! No text of specified style in document.**.20:** MIDAS in AMR

MIDAS is designed for complex ore sorting. With the help of different types of sensors, the ore can be identified according to the data received from the assorted types of cameras, 3D sensors used for analyzing surface properties; X-Ray and metal sensors. Machine is operated with a sorting program which should be taught to detect, accept and reject the material. Optical sorting is done based on the color characteristics of the material and the sorting logic of MIDAS is illustrated in Figure 3.2 [24].

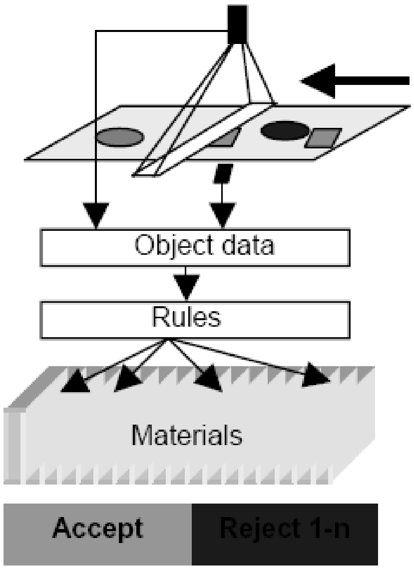


Figure Error! No text of specified style in document.**.21:** Schematically Representation of Sorting Process in MIDAS [24]

The PACT software is delivered also from the company CommaDas[R]. This software is developed for MIDAS. The data flow in the machine is showed in Figure 3.3.

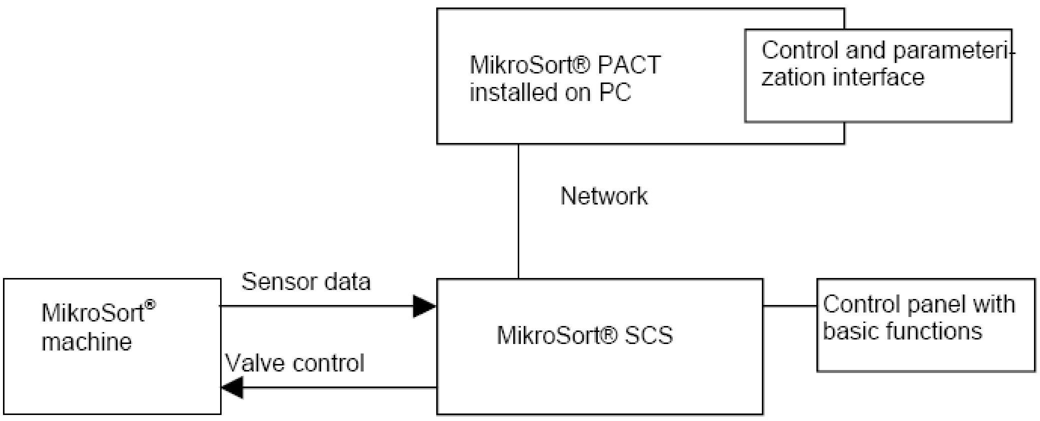


Figure Error! No text of specified style in document.**.22:** Data flow in MIDAS [24]

3.3. Optical Sorting

To make the machine ready for optical sorting, pictures are taken with the color line scan camera, which is installed on the machine. The samples are lighted from above and under the belt. This pictures show a color, which can be different from the color be seen with unequipped eye. These colors can be determined on the color diagram shown in Figure 3.4.

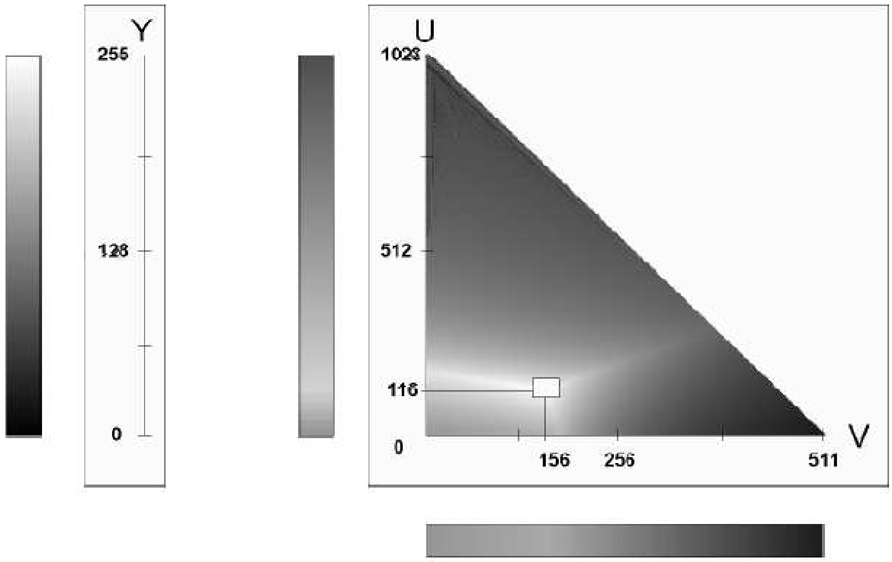


Figure Error! No text of specified style in document.**.23:** MIDAS's color model [24]

To position the right pixels, the pictures are installed one by one to the MIDAS's histogram. The program also allows possible dilatations and brightness adjustments in the color definition. The process window is seen in Figure 3.5.

After making pictures from al the groups, for example product and tailings, all the data belonging to each group is collected together. This can be shown as a cloud, or when the differences in color or brightness of the groups are high, it is better to use geometric forms. This is shown in Figure 3.6.

Depending on the color variants of the materials that are to be sorted, different color classes can be made. For example for fluorite, three groups (green, purple and tailings) are necessary. On the other hand depending on the amount of the product, it is possible to do direct or negative sorting. When the amount of tailings is less than the product, the tailings are rejected and this is called negative sorting.

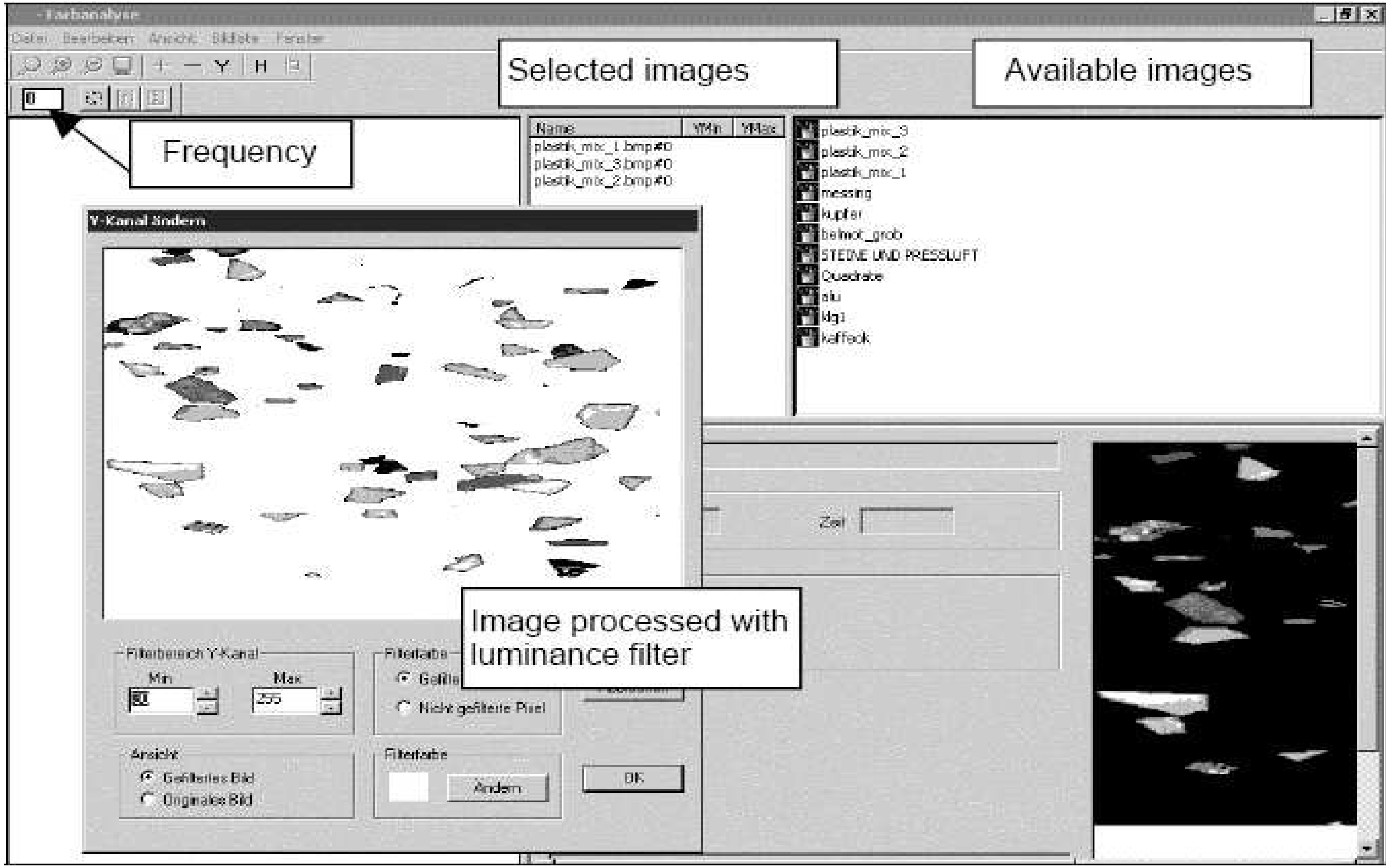


Figure Error! No text of specified style in document**.24:** Histogram window of PACT [24]

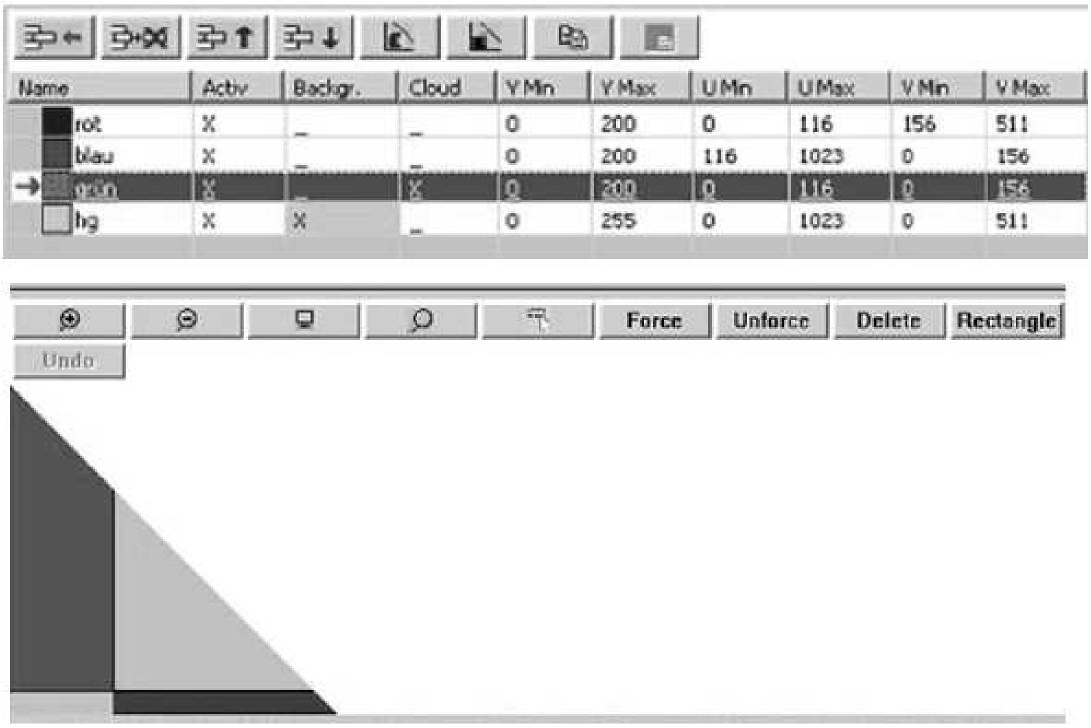


Figure Error! No text of specified style in document.**.25:** PACT color model dialog box [24]

3.4. Fluorescence Sorting

The previously described MIDAS is used for this step of the study. As also discussed in the previous sections, UV cameras are unable to identify color pictures. The best cameras which can detect UV lights are still in black-white color (gray scale). The only thing that can be detected by these cameras is to identify if the object is reflected under the UV lamp, this will be shown with white, and the rest can not be recognized by the cameras.

UV camera can only show the fluorescence material. It is possible to detect the material in this way easily. Because MIDAS can not put a difference between the background and the parts of the particle which are not florescence. For this reason, using a second sensor, either color line scan camera or 3D camera, is a must. Otherwise it can be that the air valves open later, sooner or on the corner or with an angle which is not enough to reject the material.

The planned rough description of sorting is: detecting the material with the color camera, identifying the material as fluorescent or not fluorescent with the UV-camera and ejecting with the air valves. The necessary additional equipment are UV-high resolution camera, short wave lamp, UV filter glass, UV-lamp cooling system, heat resistant and radiation isolated durable housing. The pictures of the short wave lamp and lamp's housing are shown in Figure 4.1.

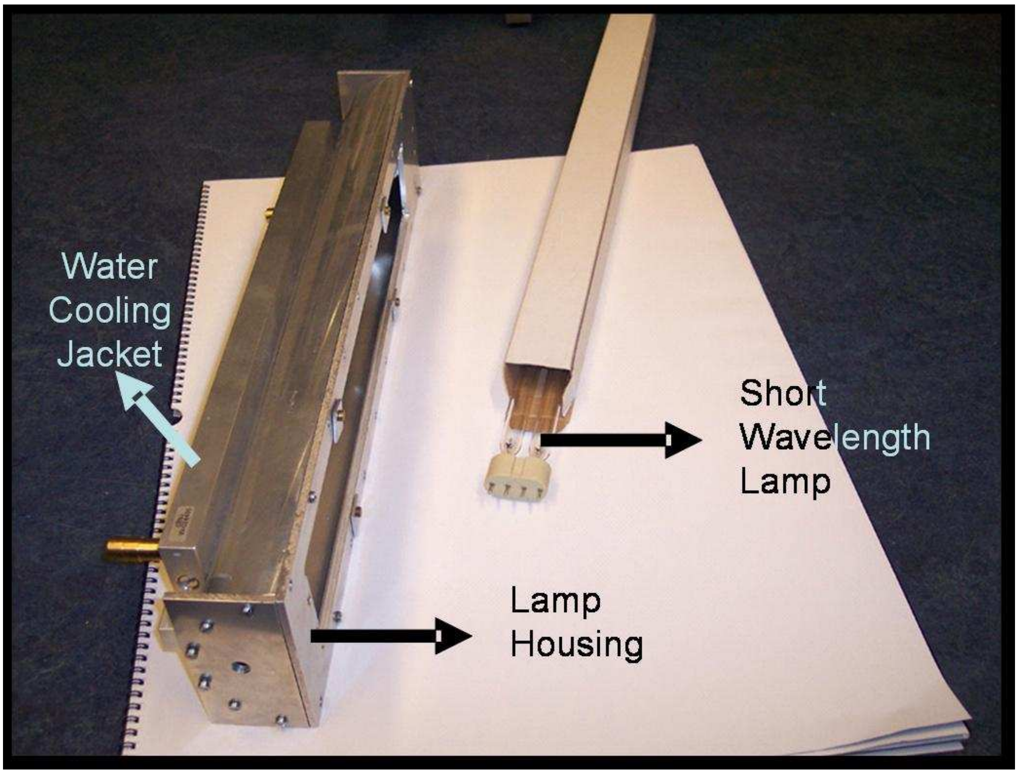


Figure Error! No text of specified style in document.**.26 :** UV-lamp and its housing

To protect the system from heat connected fires, the lamp is planned to be cooled by a water cooling system. The cooling system consist of a water tank above of the machine, a water pump, cooling fan and a water jacket letting water to travel on the surface of the UV-lamp housing.

UV light beams are hazardous for human skin and eyes. Normally heavy cotton dress and flexi glasses are enough to protect human skin and eyes. But considering the machine in a mineral processing plant also in a laboratory, instead of caring individual persons, housing the machine is more logical.

Optical sorters have dark housing in order not to let the outer light inside. The color cameras are needed to be calibrated with a constant brightness to differ the material. Constant lightening is a state of art in every sorting with surface properties. But in fluorescence sorting, housing has more meanings, not only protecting just inner side of the machine from daylight but also protecting the dangerous UV light radiating outside of the machine house. The new housing of MIDAS is shown in Figure 4.2.

Although the UV radiation is controlled by detecting device, because of any possible accident, MIDAS is covered by thick plastic curtains as shown in Figure 4.3 while the experiments are going on.

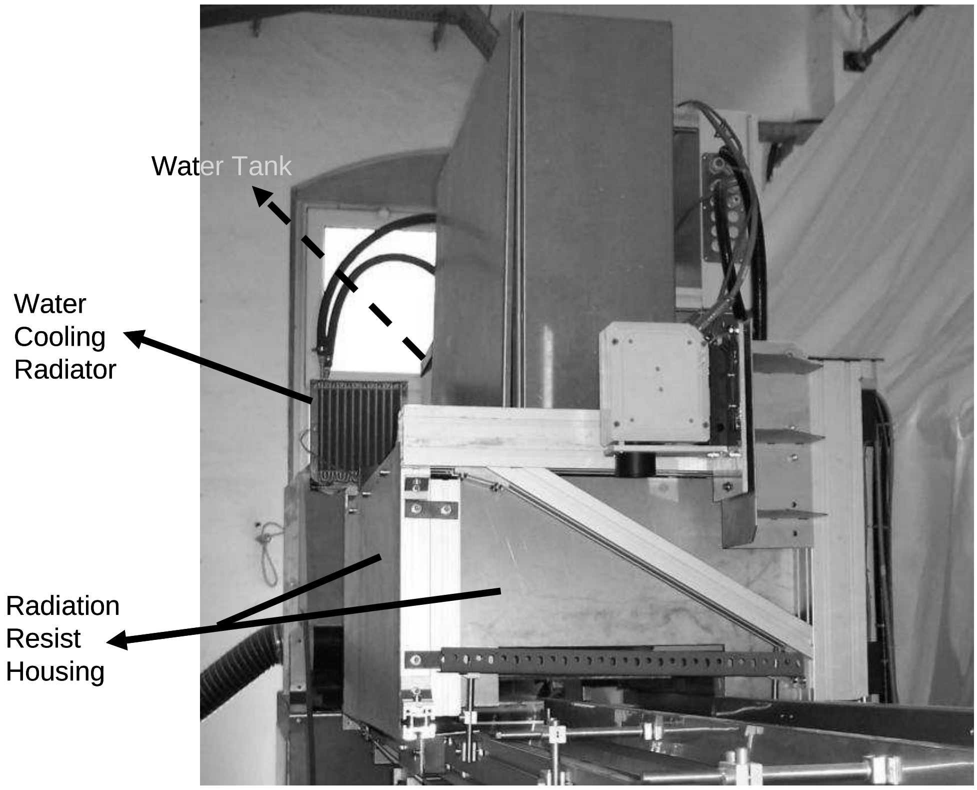


Figure Error! No text of specified style in document.**.27:** New Housing of MIDAS

Figure Error! No text of specified style in document.**.28:** MIDAS covered by a Plastic Curtain

As mentioned in the previous sections, the brightness of the objects also plays a role in sorting process. As the high sensitivity cameras are unable to isolate the particle the only determination possibility depends on the brightness difference.

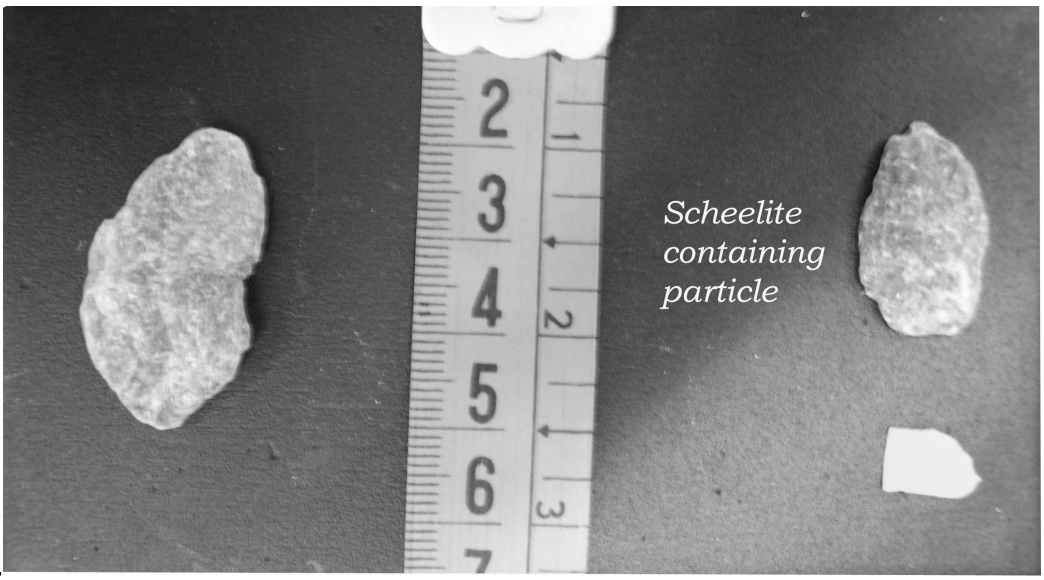
In fluorescence sorting brightness is meant whether the material excites fluorescence or not. This brightness difference is taught to PACT for fluorescence sorting.

Second of all the machine must able to isolate the particle and give the exact sizes to air valves to let them blast enough air with enough pressure. This is achieved by color cameras. The materials defined in the same method with optical sorting but without giving any definitions about waste and concentrate in order to let the machine to distinguish using the materials' fluorescence capacities. After identifying both color and brightness, it is selected to sort the material using the principle "if 1. Sensor identifies AND 2. Sensor detects, reject".

3.5. Experiments with Scheelite

3.5.1. Optical Sorting Experiments with Scheelite

Scheelite samples used in tests are from Mittersil, Austria approximately in the same color range with the mean WO_3 content of the ore is around 0.49%. There will be no difference between the detection made only with UV lamp and naked eye as seen in Figure 3.7.



.

Figure Error! No text of specified style in document.**.29:** Scheelite and tailing samples

The detections are made with the color line scan camera and the differences between the color of the both fractions (concentrate and tailings) shown in Figure 3.8. The clouds of both fractions are covering each other. With axel “Y” different brightness of the fractions are also integrated and tests are done but the results of the test work doesn’t show any success. Sorting of these scheelite samples with MIDAS configuration optical sorter is not possible and successful.

3.5.2. Fluorescence Sorting Experiments with Scheelite

A pair of scheelite minerals under the daylight and followed by UV-camera view is shown in Figure 4.4.

The mean brightness of the scheelite samples are obtained from 50 picture shots is loaded to PACT. In a brief form, the Y value of scheelite containing minerals are between 100 and 226 so the rest is defined as background or tailing. The Figure 4.5 shows the view of the materials above 60 at Y range.

As already discussed to give the right position and size of the material to the sorter, the optical color cameras are used. To maintain this, it is taught to the sorter that any thing darker than background is an object which is under 100 in the Y value. So for the sorter any object (color camera) if excites luminescence (UV-camera) must be rejected.

After various simulations the machine is ready for scheelite sorting. One of the simulation boxes of PACT is shown in Figure 4.6.

As seen in the figure the fluoresced parts of the particles are defined as scheelite (white) on the right side of the simulation box. This shows that the color and brightness definition of PACT is right oriented.

After the materials are fed to the sorter, the result is shown in Figure 3.15.

To check if the sorting was successful one of the ways is to check the samples with hand UV light. The products under UV light are shown in Figure 3.16.

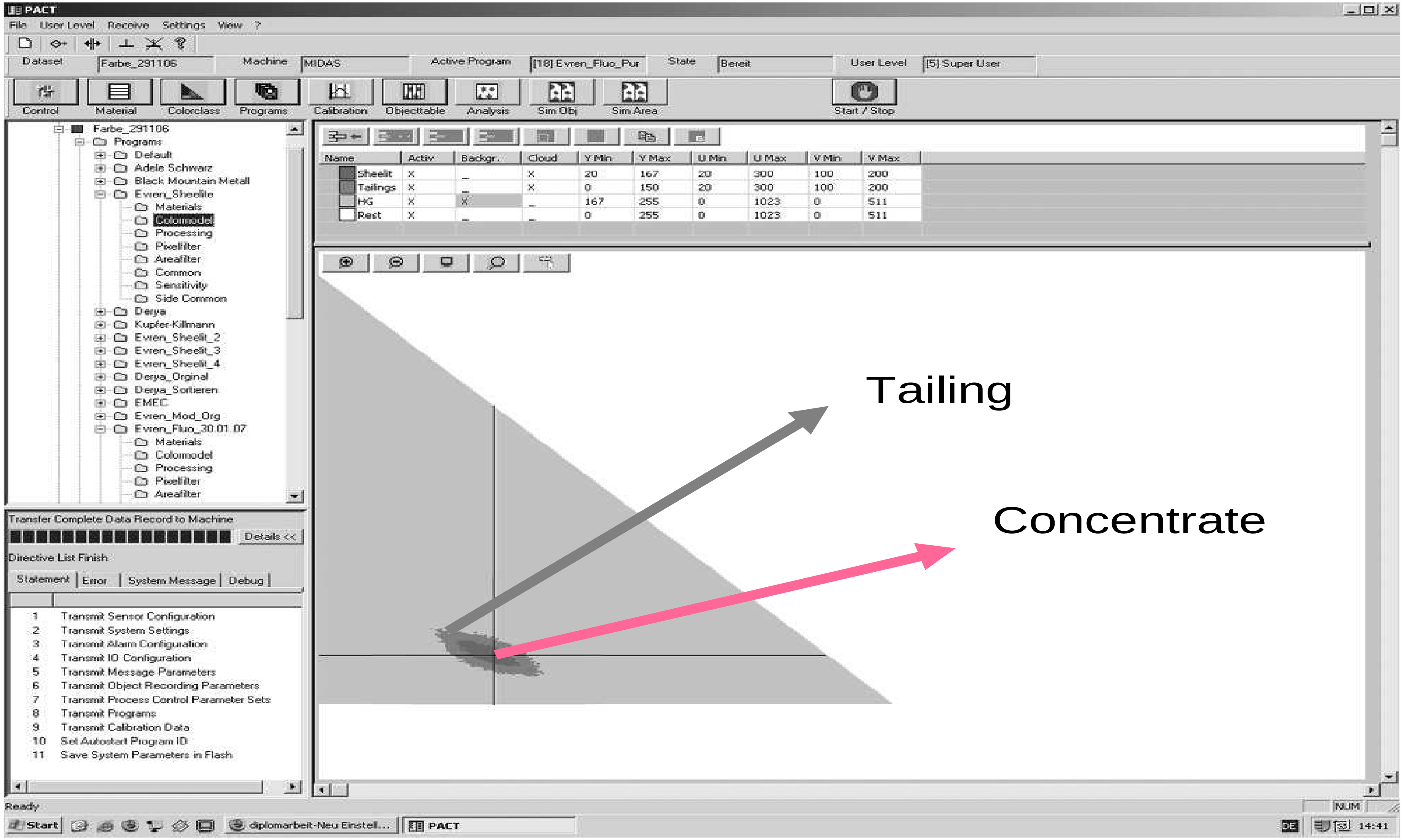


Figure Error! No text of specified style in document.**.30:** Scheelite Color Class Window

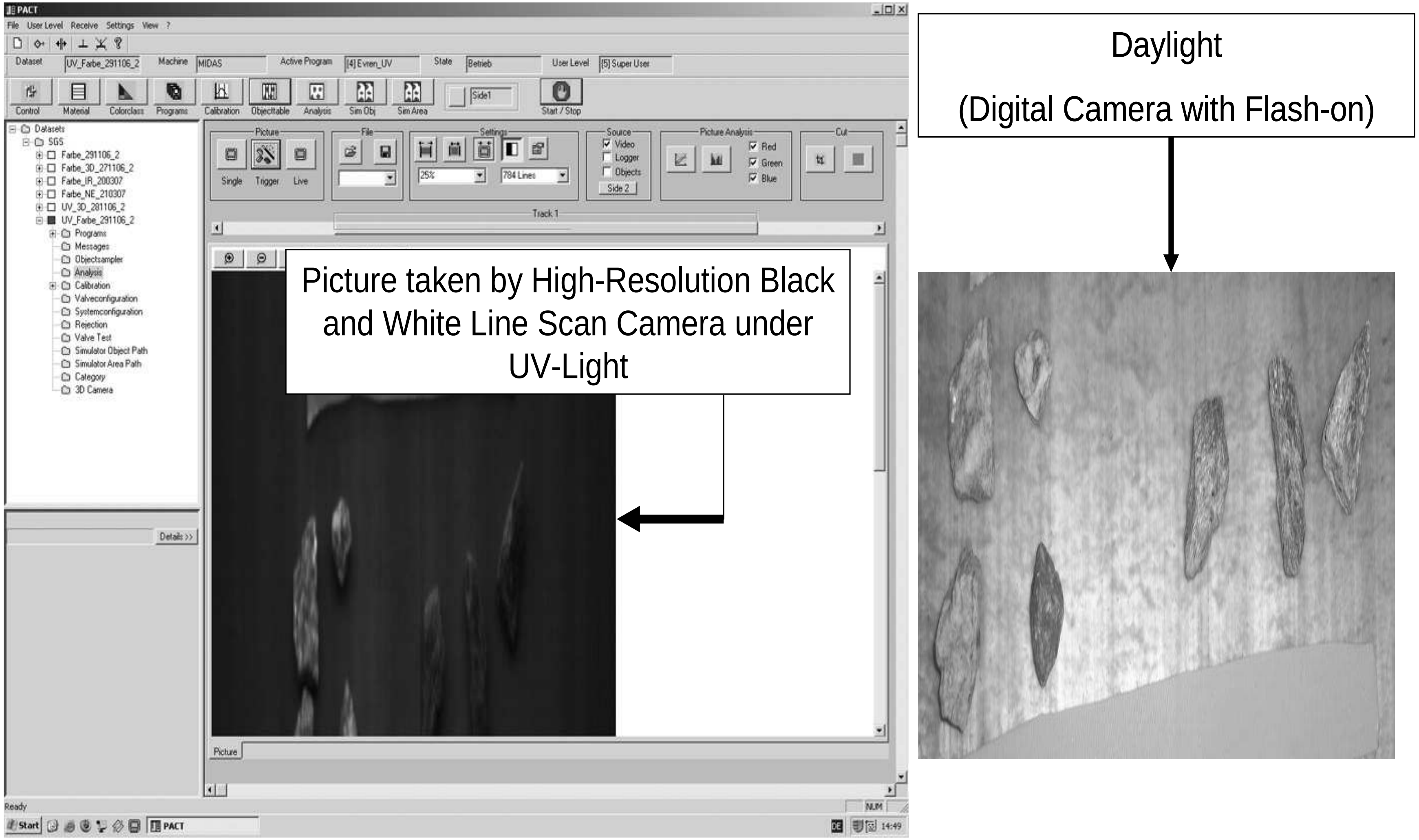


Figure Error! No text of specified style in document.**.31:** Various Scheelite samples under Day and UV light

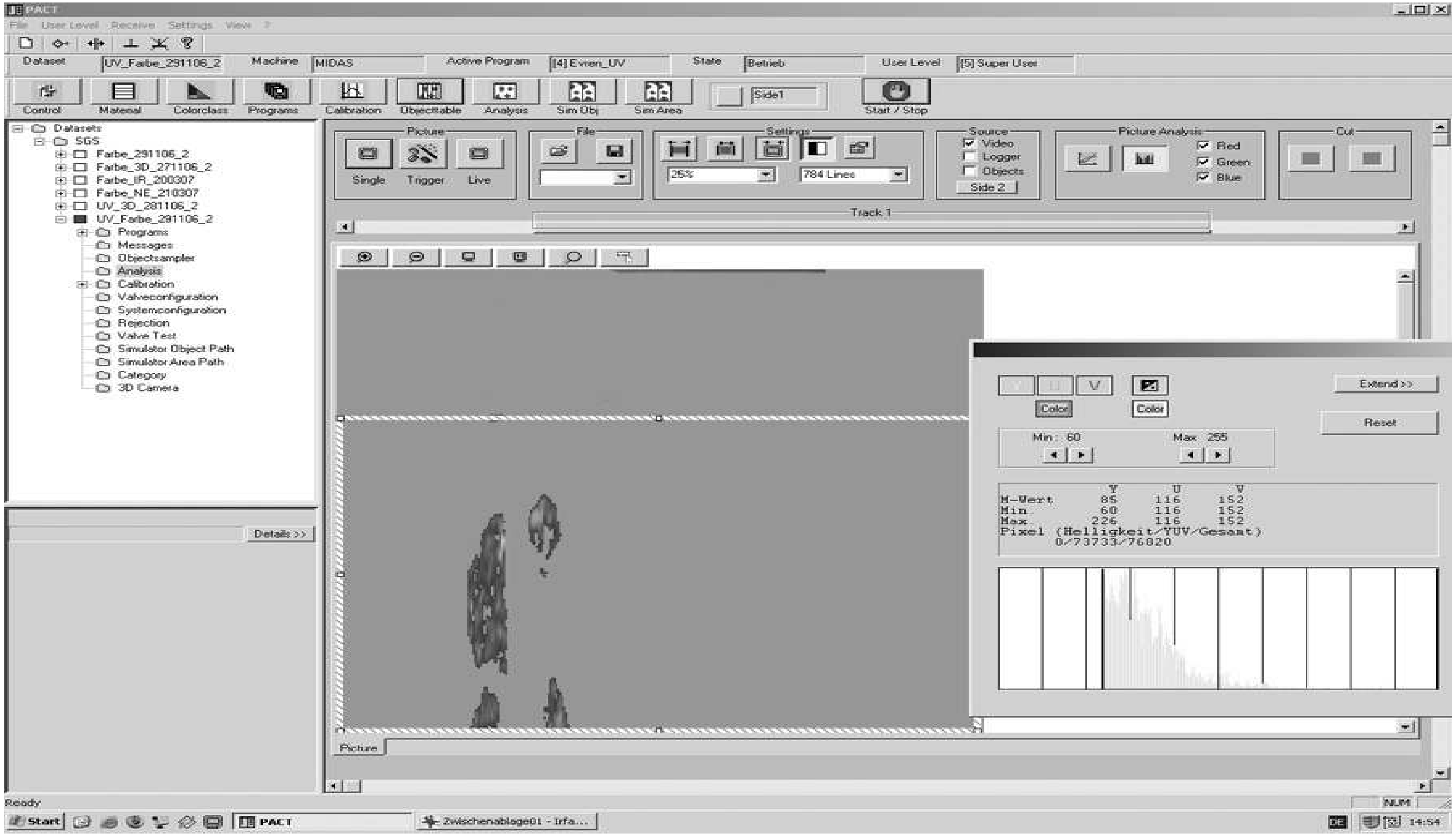


Figure Error! No text of specified style in document.**.32:** Fluorescence excited parts of the feed material

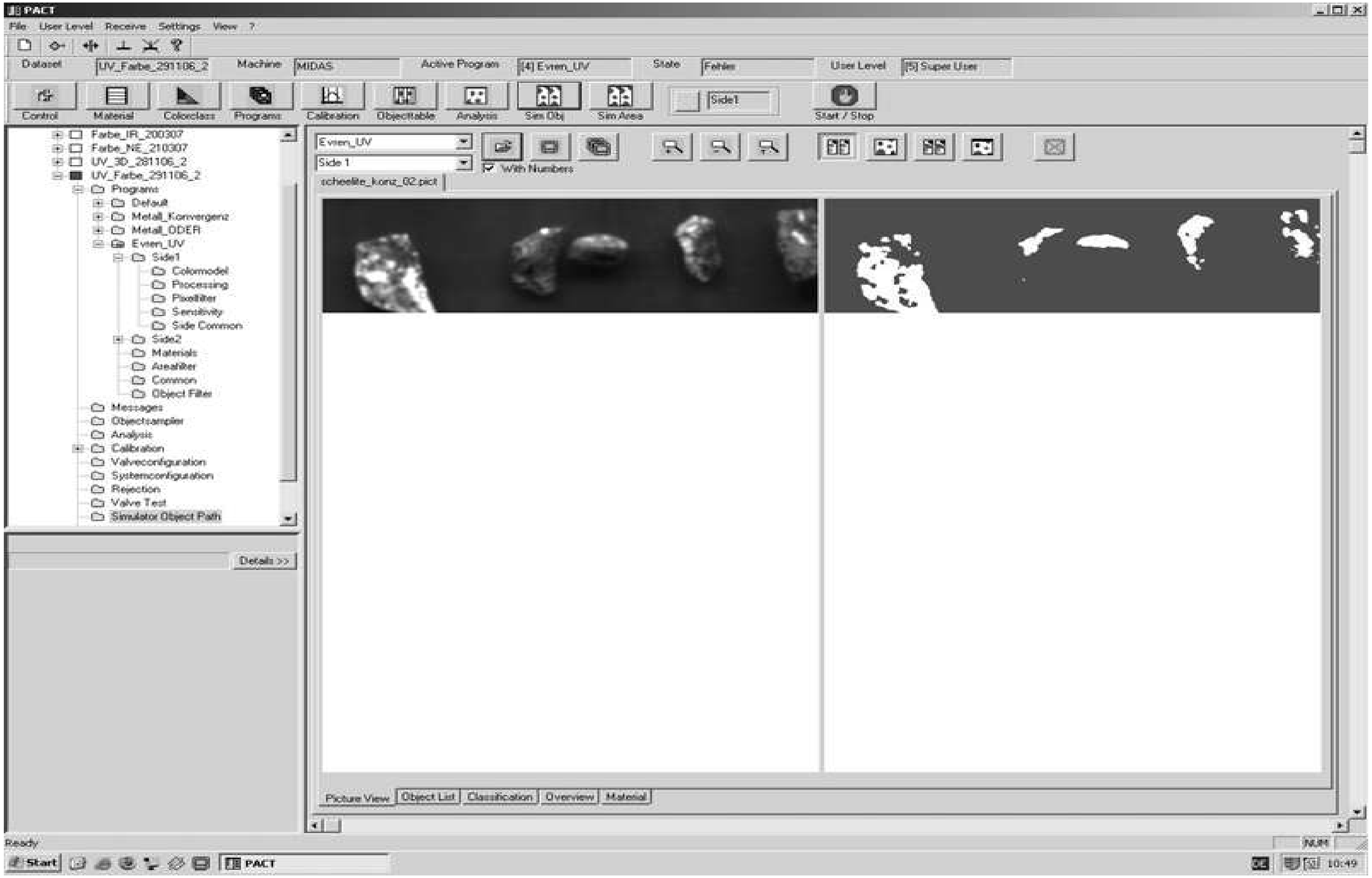


Figure Error! No text of specified style in document.**.33:** Scheelite Fluorescence Simulation box

Figure Error! No text of specified style in document.**.34:** The result of scheelite fluorescence sorting experiment

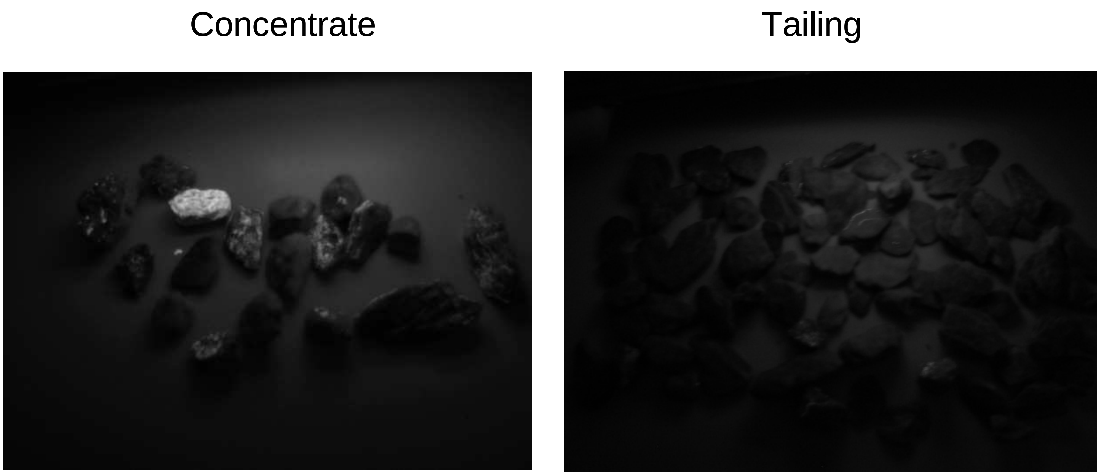


Figure Error! No text of specified style in document.**.35:** Fluorescence sorting experiment's result under UV light

3.5.3. Sensors Combination Sorting Experiments with Scheelite

The metal sensors and infrared detector are not able to get any data from the scheelite samples.

3.6. Experiments with Fluorite

3.6.1. Optical Sorting Experiments with Fluorite

The fluorite samples are obtained from Sachtleben Bergbau Services (Clara Mine) in Wolfach, Germany. The plant is located in the Kinzig Valley (Central Black Forest). The ROM fluorite ore contains 5-10 wt % $BaSO_4$ and 35-45 % CaF_2. The associating minerals are mostly, gneiss, quartz and ferrous carbonates [23]. Samples are in the range of -31.5+10 mm size.

The colors of fluorite and the associating minerals are very easy to distinguish by naked eye. Fluorite is occurred in two colors in our samples; light-purple and light-green. The associating minerals split colors around brown, but sometimes hard to distinguish from dark purple. Different samples from different fractions were detected and for these three fractions, three color classes were defined. These color classes are shown in Figure 3.9.

As seen in the color model there are some intersections but none of the material color is subsume of the other cloud. Fluorite is more glasslike mineral so it reflects more light then the tailings which adsorb more light. For example as seen in Figure 3.10 the color range of the tailings are able to be seen between 112-206 in V axel, normally the V amount can be between 0-511 (Figure 3.4). The amount of “U”, “V” and “Y” are shown after each scan but by using clouds, the amount of the “U” and “V” will be automatic registered. The amount of “Y” (for brightness) is shown on a table after each scan. In Figure 3.10 this amount can be seen. The amounts of Y max and Y min are entered manually. For each color class about 50 photos are taken and scanned.

After adjustment of the color ranges and material definitions, the sorter is ready to operate. PACT has a simulation option to check if the color classes are working. This option enables to control if the color classes are defined in the right way, detected and sorted in the right color class. This will be done on pictures made before. A simulation window picture is shown in Figure 3.11.

The original pictures are shown above the screen and the ones under them are made by the simulator. After various simulations, a mean value of color percentage per material is calculated. These percentages are installed to material definitions for a successful sorting. Briefly it has to be defined to the sorter, which material has how much from a color, for example above 55% green containing particle can be defined as green. Material definition box of PACT is shown on the figure 3.12.

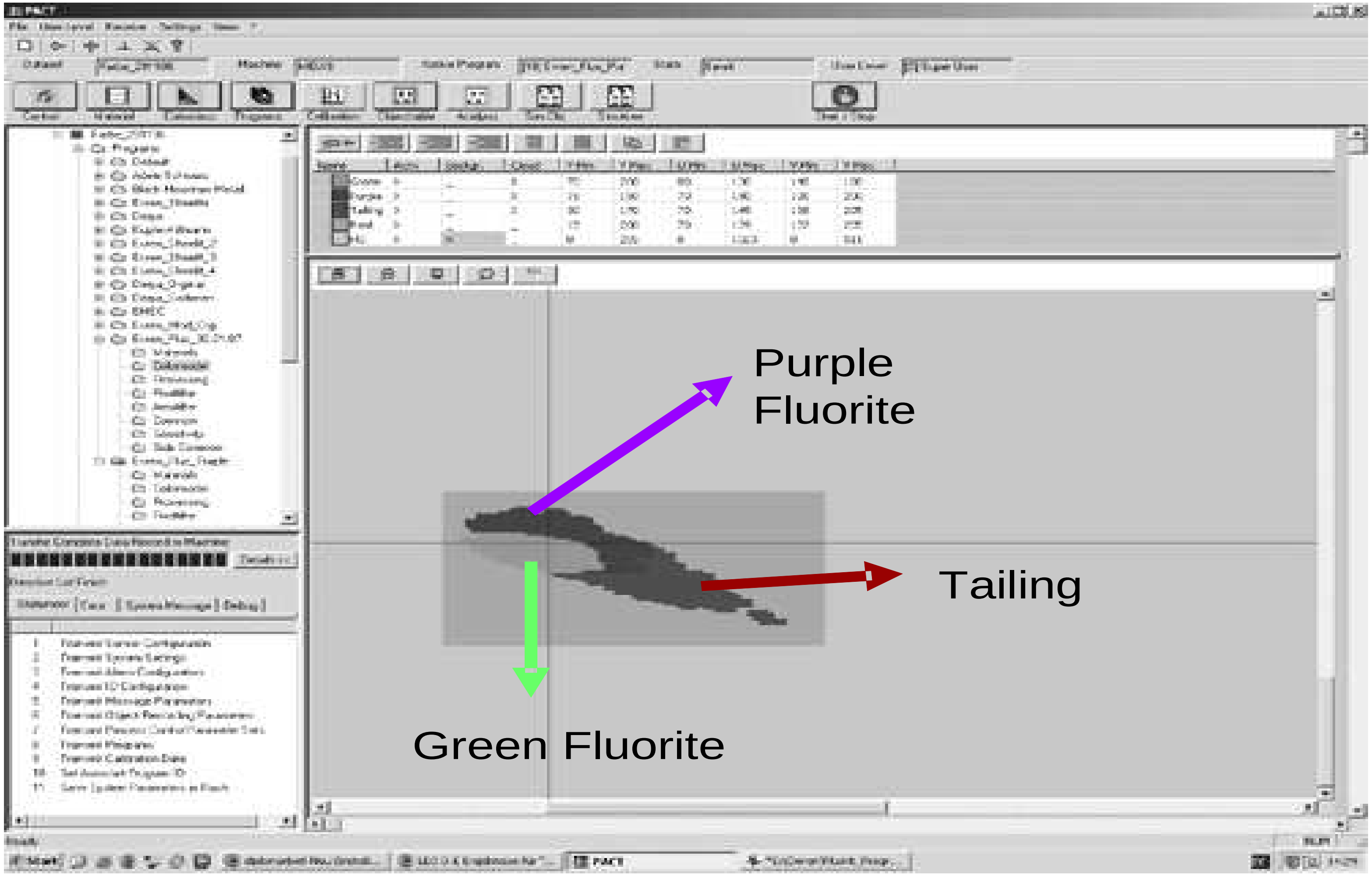


Figure Error! No text of specified style in document.**.36**: Fluorite Color Class Window

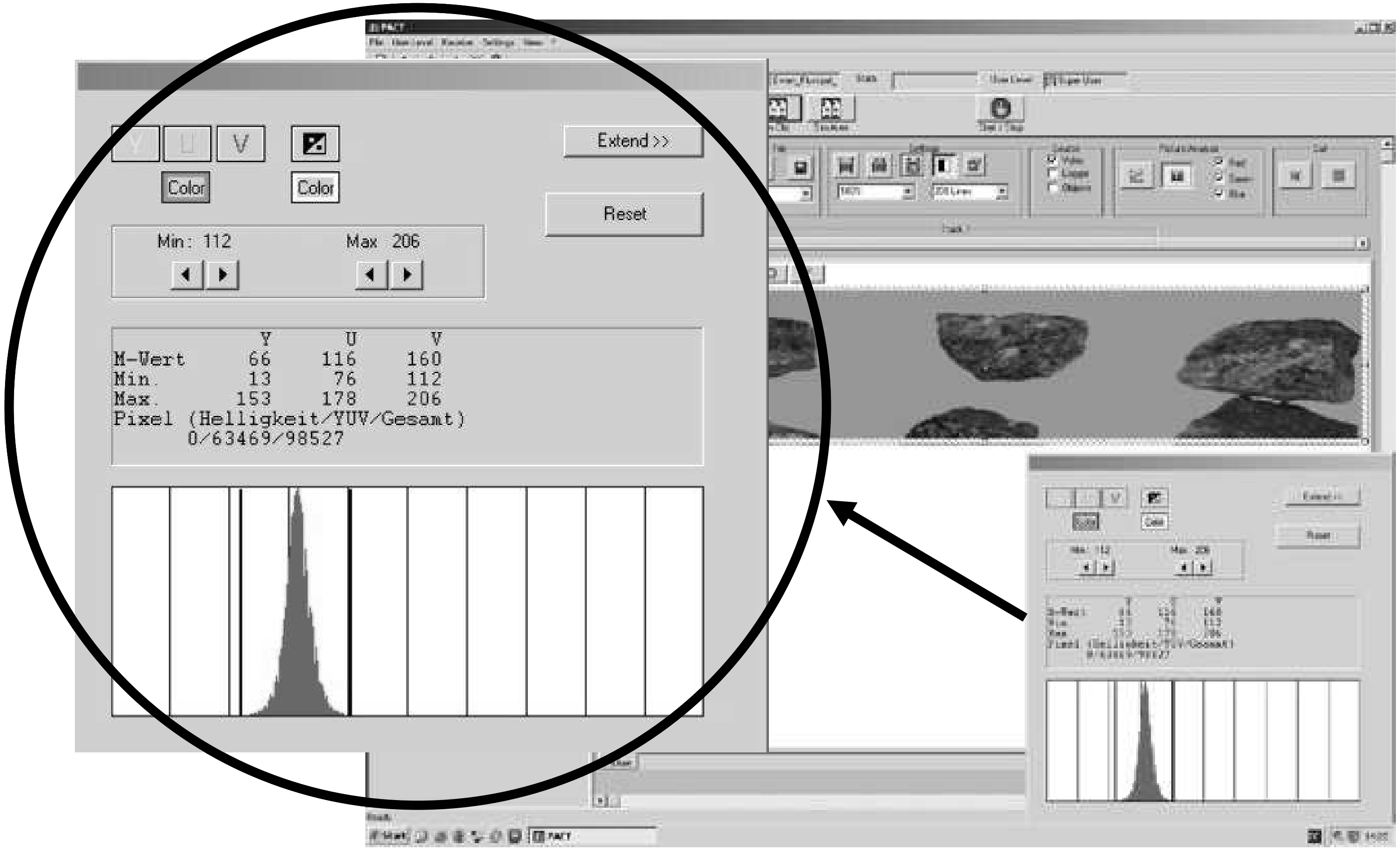


Figure Error! No text of specified style in document.**.37:** Adjustment V value of a tailing fraction

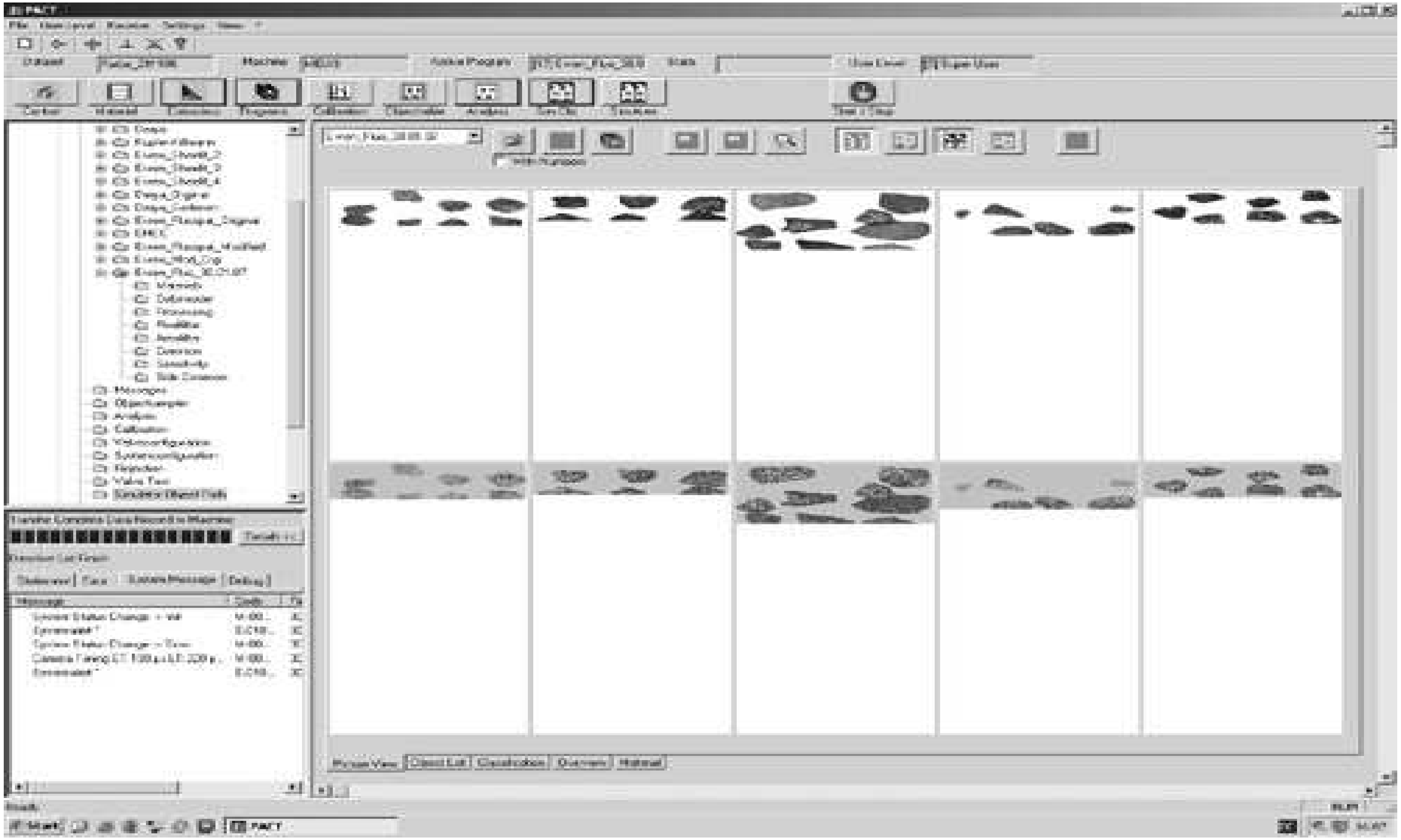


Figure Error! No text of specified style in document.**.38:** PACT simulation example

Figure Error! No text of specified style in document.**.39:** PACT material definition window

3.6.1.1. Green Fluorite Separation

Three color classes are defined: green, purple and tailings for fluorite. These three fractions are separated from each other.

The aim of the first part was to separate green from the rest. Before beginning the test work, randomly 100 particles are taken from 5 kg of material as a feed for MIDAS and per hand sorted. There are 22 particles green. The materials are sent to MIDAS on a transparent conveyor belt. The speed of the conveyor belt is during the whole test work stable and 2 m/s. The result of this sorting is shown in Figure 3.13.

Figure Error! No text of specified style in document.**.40:** Optical Sorting of fluorite

MIDAS is able to separate the 22 green particles from the others with a recovery of 100%. The material definition of the successful experiment for “green” is given in Table 3.1. According to this table on the surface minimum 24.24% and maximum 95.64% green color containing particles are defined to be green for the sorter.

Table Error! No text of specified style in document.**.5:** Green materials color distribution for PACT

	Green	Purple	Tailings
Min	24,24%	2,10%	2,25%
Max	95,64%	31,56%	44,20%
Average	67,22%	15,03%	17,75%

3.6.1.2. Purple Fluorite Separation

The aim of this part is to separate the purple particles from rest of the tailings. The samples which are separated from the green particles are fed into the sorter again. There are 15 purple particles in the feed, as seen in Figure 3.14; there are 3 particles from the tailings' fraction in the concentrate and 2 particles from the product fraction in the tailings. In this step from 15 particles in feed, 13 are separated successfully. There are 3 particles from tailings fraction in the product side and the recovery was about 87%.

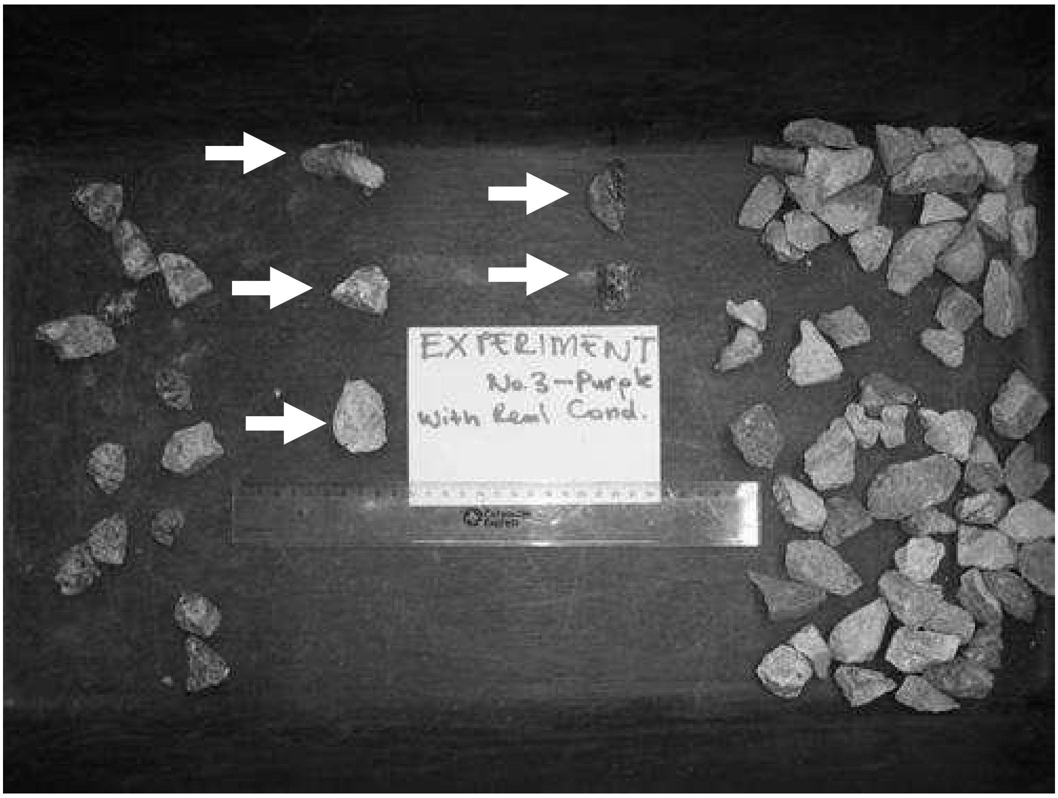


Figure Error! No text of specified style in document.**.41:** Optical sorting of purple particles

Table Error! No text of specified style in document.**.6:** Purple materials color distribution for PACT

	Green	Purple	Tailing
Min	2,85%	48,42%	7,05%
Max	32,63%	83,73%	39,49%
Average	14,75%	66,99%	18,26%

3.6.2. Fluorescence Sorting Experiments with Fluorite

Four fluorite samples, two from tailings and two from the concentrate fraction are fed to the sorter. The alignments of the particles are shown in Figure 3.23.

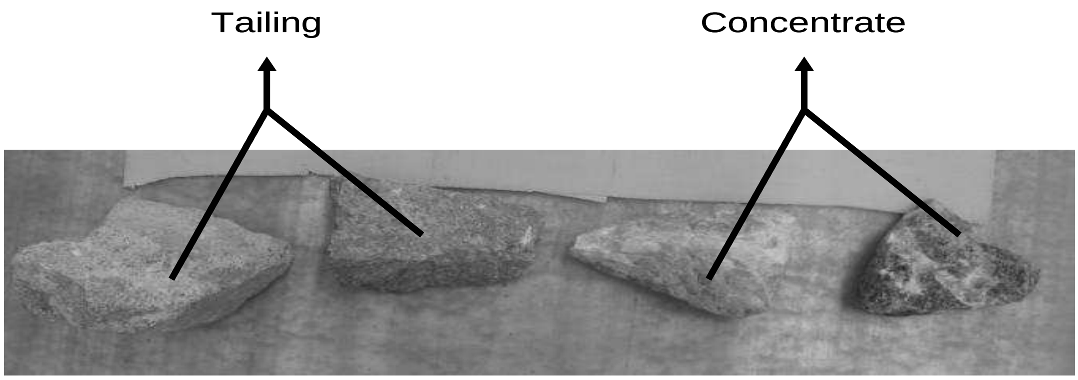


Figure Error! No text of specified style in document.**.42:** Fluorite samples alignment on the conveyor belt

This is done to see if there will be a fluorescence occurring under UV lamp of MIDAS. The fluorescence of the materials in PACT's dialog box is shown in Figure 3.24. As seen from the figure the waste tailings are still can be seen above 95 in Y value. So it is not possible to distinguish tailing and concentrate for the sorter. After establishing the experiment it has seen that there is no sorting possible.

3.6.3. Sensors Combination Sorting Experiments with Fluorite

The metal sensors and infra red detector are not able to get any data from the fluorite samples.

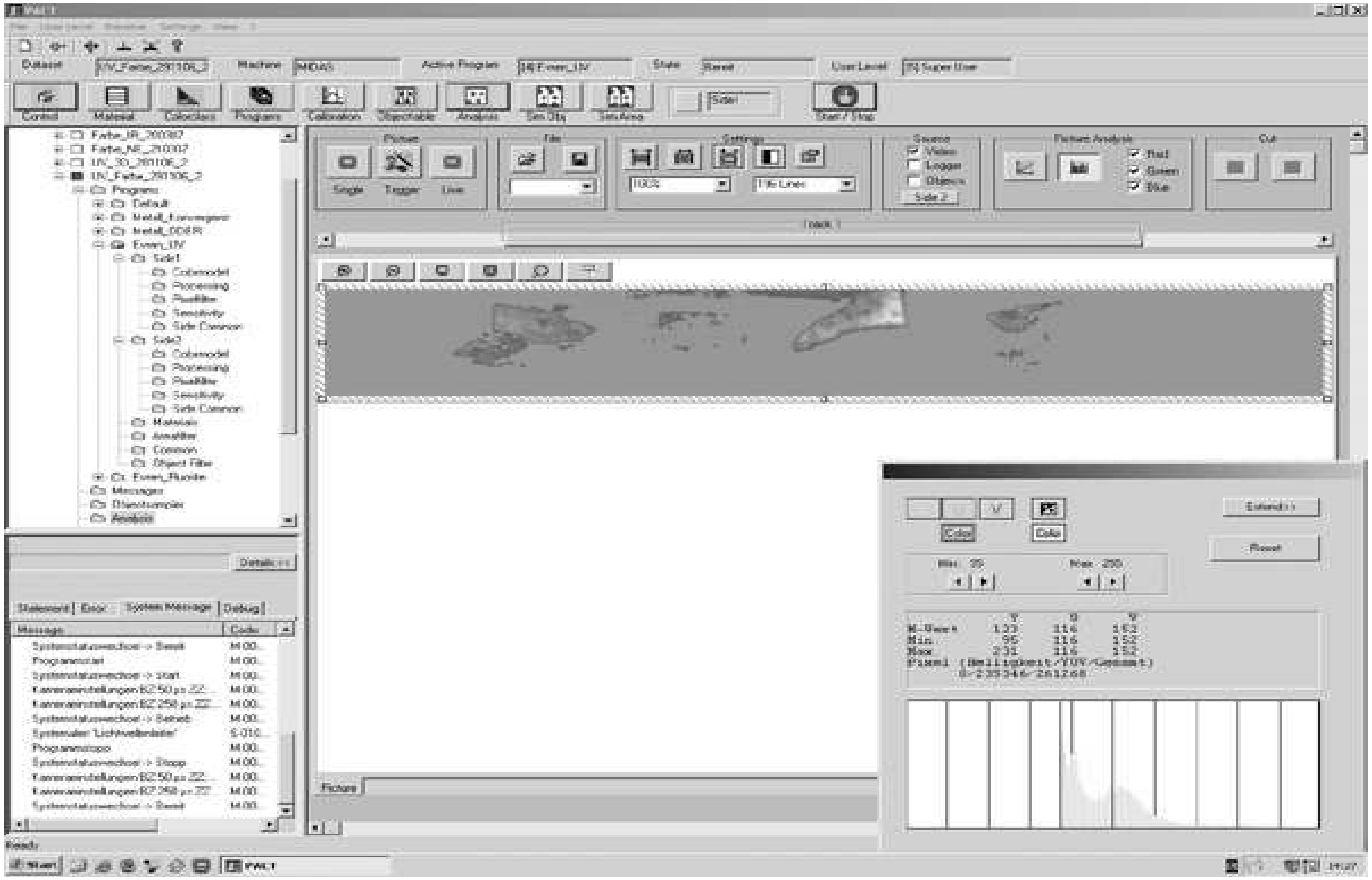


Figure Error! No text of specified style in document.**.43:** PACT dialog box for feed material for fluorite experiment

4. CONCLUSIONS

Known optical sorters sometimes are not enough for some materials. The aim of this study is to use new sorting methods for two different minerals, namely fluorite and scheelite that belong to fluorescent minerals by using their different properties and try to find a suitable sensor to sort them.

For high fluorite and scheelite sorting efficiencies, most of the sensors are studied and when necessary, the combination of two or more sensors' effect on the sorting are investigated. In this study, present equipment configuration and the set ups that are applied; fluorite is successfully sorted with the optical sorting machine while scheelite sample is not able to be sorted by optical sorter. Since automatic sorters can be applied either as pre-concentration equipment or final concentration, both adjustments are applied for fluorite. The results for pre-concentration adjustment are shown in Table 4.1 and the results of the final product adjustment are shown in Table 4.2.

Table Error! No text of specified style in document.**.7:** Results of pre-concentration adjustment

	%	%F	%F Recovery
Pre-Conc.	51,41%	40,70%	96,42%
Tailing	48,59%	1,60%	3,58%
Total	100,00%	21,70%	100,00%

Table Error! No text of specified style in document.**.8:** Results of final-concentration adjustment

	%	%F	%F Recovery
Final-Conc.	25,95%	47,70%	37,47%
Tailing	74,05%	27,90%	62,53%
Total	100,00%	33,04%	100,00%

As seen from the tables there is a small difference between concentrate contents, but a very big difference on the tailing side. Color sorting doesn't seem to be efficient in this particle size to have final concentrate. 96.42% recovery is more then the best physical enrichment methods.

On the other hand, under the same conditions explained above, scheelite is successfully sorted from the tailings with the fluorescence sorter. The experimental results are shown in Table 4.3. The experiments aiming to distinguish fluorite concentrate from tailings are not successful.

Table Error! No text of specified style in document.**.9:** Scheelite sorting experimental results

	%	%W	%W Recovery
Concentrate	25,07%	14,40%	90,15%
Tailing	74,93%	0,49%	9,85%
Total	100,00%	4,37%	100,00%

Although sorting recoveries of minerals are very high, there is still some mineral loss in the tailing side. This can be improved size reduction and more machine modifies for example 2 side cameras, chutter machines or etc.

When the pre-concentration results are considered, disposing 48.59% of material in fluorite sorting and 74.93% of the material in scheelite sorting as waste results in the same percentage decrease in the enrichment costs. Thus, the amount of transported material decreased together with the transportation cost. The company's yearly profit will also increase, since less material will go to the concentration plant (mostly flotation),

This study is mostly concerned on the electronic sorting properties and possibilities of the minerals, no investigations on the other enrichment processes for the feed material, products or tailings are done.

The future work is recommended to be done with other type of UV lamp which can be more effective for luminescence exciting on fluorite samples. As already described in the previous sections, the cameras which are able to catch UV reflections are still in gray scale. With the developing technology UV excitation can be identified and valued by the color, which makes UV color excitation sorting possible.

REFERENCES

[1] **Wills, B.A.,** 1997. *Mineral Processing Technology*, 6.Ed., Butterworth-Heinemann, Oxford.

[2] **Salter,.J. D., and Wyatt, N.P.G**.,1994, Sorting in the Minerals Industry: Past, Present and Future, *Minerals Engineering*, pp.779-796

[3] **Sivamohan, R.; and Forssberg, E.,** 1991. Electronic Sorting and Other Preconcentration Methods, *Minerals Engineering*, pp.797-814

[4] **Wotruba, H. and Riedel, F.,** 2006. Sensor based Sorting of Metalliferous Ores – an Overview, *Sensorgestützte Sortierung*, Eurogress, Aachen, March 28-30.

[5] **Wotruba, H.,** 2006. Sensor sorting technology – is the minerals industry missing a chance, *XXIII International Mineral Processing Congress*, **Vol.1**, September 3-8.

[6] **Wedel, M.D.,** 2007. Optische Sortierung von mineralischen Rohstoffen,

http://www.mogensen.de/de/pdf/Mineralische_Rohstoffe_deutsch.pdf, February 12

[7] http://www.steinert.de/uploads/media/Induktionssortiersystem.pdf, 2007, May 6.

[8] http://pages.ta.tudelft.nl/live/pagina.jsp?id=dd1900a4-acbc-4662-a267-c48181 27 5fc d&lang =en, 2006, November 18.

[9] http://www.lla.de/en/index.php/content/view/25/53/, 2006, December 16.

[10] **Marfunin, A. S.**, 1979. *Spectroscopy, Luminescence and Radiation Centers in Minerals*. Springer, Berlin.

[11] **Broicher, H.** , 2001. Anwendung der laserinduzierten Fluoreszenz-Analyse für das Sortieren mineralischer Rohstoffe, *2.Kolloquium Sortieren Innovationen und Anwendungen,* Berlin, Oktober 11-12.

[12] http://www.galleries.com/minerals/fluoresc.htm, 2006, November 13.

[13] http://www.smalloak.com/papers/sorting.html, 2007, January 5.

[14] http://www.compacsort.com/wa.asp?idWebPage=14832&idDetails=107, 2007, May 1.

[15] http://www.wendtcorp.com/pdf/e-scrap/e-scrap_sorting.pdf, 2007, February 3.

[16] **Dammer,B., and Tietze,O.,** 1928**.** *Die Nutzbaren Mineralien mit Ausnahme der Erze und Kohlen*, pp.2-3, Enke, Stuttgart

[17] **Gleason, S.,** 1960. *Ultraviolet guide to minerals*. D. Van Nostrand Company, Inc. New York

[18] **Schuler,A.,** 1986. Anreicherung von Scheelite aus den feinkörnigen Aufbereitungsabgängen des Scheelitbergwerks Uludag untersucht werden, *Diplomarbeit*,Institüt für Aufbereitung, Aachen.

[19] http://www.usgs.gov/pubprod, 2006.

[20] **Götte,J**., 1980. Untersuchungen über die drückende Wirkung eines Polysaccharids bei der Flotation von drei ausgewählten Scheeliterzen, *Diplomarbeit*,Institüt für Aufbereitung, Aachen.

[21] **Burchard,E.F**., 1937. *Industrial Minerals and Rocks (Nonmetallics Other than Fuels),* the American Institute of Mining and Metallurgical Engineers, New York.

[22] **Leeder, O.,** 1979. *Fluorit*. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig.

[23] **Sötemann, J.,** 2000. Processing of Baryte and fluorspar-Separation of complex Raw Ores with increasing quality standards, *Aufbereitungstechnik*, pp.271- 277, vol.41

[24] **CommoDaS handout**, Manual for Setup Technicians

BIOGRAPHY

Evren Ören was born in Istanbul at July 2, 1980. He has studied until the 8. grade beginning with Mustafa Kemal Atatürk Primary School following Marmara College and Istek Vakfi Özel Acibadem Lisesi in Istanbul.

He has moved to Bursa because of his fathers business and studied in Tan College until starting to study in Istanbul Technical University.

He studied in Mining Engineering Department and graduated in 2003. Following the graduation he started to study as a master student in Mineral and Coal Processing Program in Institute of Science and Technology of Istanbul Technical University. He went to Aachen in Germany as an exchange student and he got another engineering degree and diploma additional to his M. Sc. Degree (Istanbul Technical University) from Aachen University of Technology.

He is interested in sensor based sorting and new enrichment technologies in mineral processing field in his professional life.

Evren Ören can speak fluent English and German additional to his mother tongue Turkish.

Evren Ören makes winter sports especially snowboarding and has a huge interest about the cars. He also likes to play basketball, watch movies and speak about politics. He believes that the aim in life must be “to be better” in life.

His favorite song is “Soldier of Fortune” from the band Deep Purple. His favorite writer is Carl Sagan. His favorite movie is “Taxi Driver” with Robert De Niro.

Jedi Master Yoda’s *“do or do not, there is no try”* is his favorite quote (Star Wars).