DOI: 10.29202/nvngu/2018-5/3

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RADIOMETRIC SORTING TECHNIQUES FOR MINING WASTES FROM OUENZA IRON MINE (ALGERIA)

Purpose. The research work deals with the characterization and the valorisation of waste rocks from Ouenza iron mine by physical methods. The chemical and mineralogical analyses carried out on the three categories taken from the dumps, allow us to distinguish three categories of materials on all the landfill sites, namely: hematite, which represents 30 %, marl 30 %, and limestone 40 %. These cause a problem of management and distribution of rocks at the surface. The objective of this research is to search for ways of removing the waste rocks from the iron mine of Ouenza.

Methodology. To identify these waste rocks, a characterization was performed by XRD of the different categories and the initial sample, the chemical analysis of the three categories of materials from the dumps of Ouenza iron mine by FX. Tests to measure the mass attenuation coefficient of waste rocks samples by transmitting a γ-beam in thin geometry were applied. Attenuation was studied for the 122, 244, 344 and 661 KeV energies emitted by the point sources of ^{152}Eu and ^{137}Cs, respectively.

Findings. Different raw samples were analysed by DRX and FX. The obtained results show that the mineralogical composition includes: calcite, quartz and hematite. The best results are achieved with the following parameters: the thickness of the samples between 80 and 90 mm, the sample captures the whole gamma beam, and the range of energies is between 122 and 661 KeV, which strongly contributes to the radiometric separation of waste rocks from the iron mine of Ouenza, Algeria.

Originality. It is possible to apply the radiometric method. This process allows selective sorting of the waste rocks of Ouenza using γ-rays at different energies, taking into account the thickness and the iron content of the samples. The separation technique is simple and economical and does not require investments in heavy industrial equipment.

Practical value. Iron ore is in great demand in the global market. However, waste rocks must be sorted and valued so that the product is merchantable. The iron ore processed by the technique suggested meets industrial requirements and international standards, in particular, in the iron and steel industry; the iron content is 67.13 %.

Keywords: *waste-rock management, radiometric method, γ-rays, Ouenza mine*

Introduction. To reach the mineralized zone, the exploitation of the Ouenza-Algeria deposit generates large quantities of solid mining wastes that are stored at the surface near the mine site in the form of stacks, commonly called waste rock dumps.

Free-soil waste poses land-use problems for exploration and exploitation of deposits because of their *in-situ* properties. Waste rock is piled up in huge slag heaps, which requires appropriate measures to prevent landslides, soil instability, and the protection of workers, the public and the environment [1].

The objective of this work is the possibility of treatment and disposal of waste rock from Ouenza, taking into account the nature of the stock and the complexity of the mineralogical composition of free waste rock and the physico-chemical heterogeneity of these materials. To solve this problem we propose the use of a complete characterization to identify waste rocks and a valuation by the radiometric method.

In order to preserve the environment against pollution due to the harmful effects of dust and liquid effluents from mining residues, the valorization of these ores will allow, on the one hand, increasing the industrial reserves of the deposit and, on the other hand, increasing the life of the mine [2, 3].

The separation of useful minerals from gangue is performed through the use of methods based on the properties of certain minerals to emit radiation (emission-radiometry methods), or to attenuate radiation (absorption-radiometry methods). Radiometric emission methods use natural radioactivity or luminescence of minerals, and radiometric absorption

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methods use X-ray and neutron and gamma radiation.

The influence of the thickness of the calibrated ore on the degree of absorption of the γ-rays, as well as that of the iron content of a calibrated sample, on the absorption the intensity of the γ-rays is carried out in an installation laboratory [4].

Materials and Methods. ***Identification of the deposit. Geographic location.*** The mine of Ouenza exploits iron ore by opencast method. It is located 90 km north of Tebessa city (Fig. 1, *a*) and 190 km south of the city of Annaba where the iron and steel complex of El Hadjar is located, the sole destination for iron ore production from the mine, to undergo various metallurgical treatments.

Sample collection. The purpose of the sampling is to provide information on an overall plot, with a known and acceptable level of reliability. To study the characteristics of this plot, it is often easier and faster to analyze a sample. It is then necessary to choose a subset which represents as closely as possible the characteristics of the whole plot. The plot is therefore divided according to the Google Earth image into 12 points, according to the points of intersection of the GPS coordinates. The sample collection points are fixed on discharge 845 and 920 of free waste rock as shown in Fig. 1.

Characterisation studies. According to the mineralogical composition, there are four predominant types of material in the free-blast, namely: rich iron ore (RI); poor iron ores (PI); marl and limestone.

Determination of elements by X-ray fluorescence. The X-ray fluorescence analysis of the different samples taken from landfills is carried out at the ORGM-BOUMERDES research center laboratory.

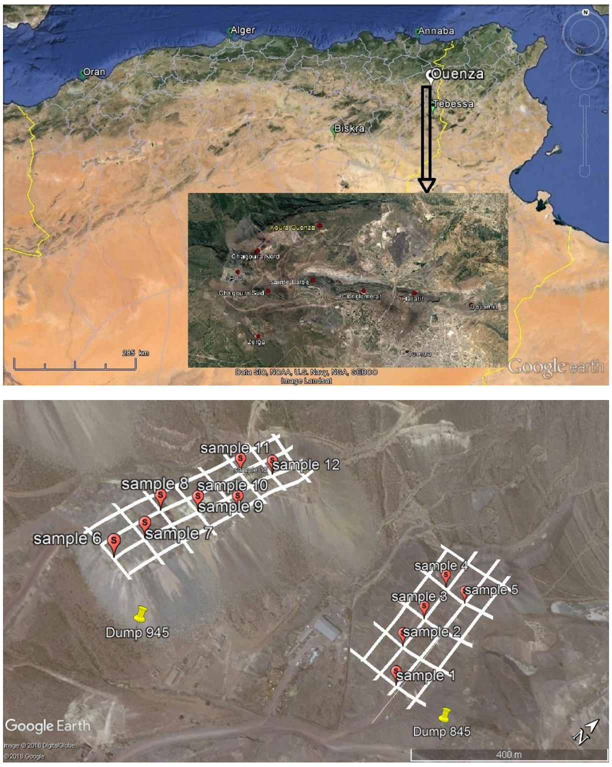


Fig. 1. Geographic location with Sample collection points

Characterization by X-ray diffraction of samples. The samples taken from the free waste dumps of Ouenza deposit are finely ground and analyzed by X-ray diffraction (XRD). The spectra obtained are composed of several peaks corresponding to the mineralogical composition.

Radiometric concentration process. The recovery of these waste rocks is necessary, because it will allow, on the one hand, increasing the industrial reserves of the deposit and, on the other hand, reducing atmospheric pollution in the region. The climate of the region of Ouenza is semi-arid low rainfall. As a result, it is more expectable in these climatic conditions that the radiometric sorting is the method that best corresponds to the separation of the calibrated franklin of Ouenza.

There are several techniques for concentrating dry oxidized iron ores: magnetic separation, magnetic, radiometric, photometric and electrical roasting. The radiometric concentration process, being comparatively low in investment, makes it possible to extract a large proportion of non-metallic materials from calibrated ore.

Radiometric concentration methods are based on the difference between the radiometric properties of useful mineral components, namely, their ability to emit, reflect, and absorb corpuscular and wavy radiation [5].

Determination of the linear attenuation coefficient of waste rocks samples by transmission of γ-beam. The present experiment consists in determining the total linear attenuation coefficient in iron ore rocks of different concentrations by studying the attenuation of a photon beam through the samples [6–8].

For this, we use the basic equation connecting the incident beam to the transmitted beam given by the Beer-Lambert relation [9]

$$I = I_0 e^{-\mu x}, \tag{1}$$

where μ is the total linear attenuation coefficient given in (cm^{-1}); x is thickness of the sample in the beam incidence direction given in (cm); I is attenuated intensity of the beam of energy gamma E; I_0 is intensity of energy gamma beam E before attenuation; $e^{-\mu x}$ is the coefficient of transmission.

From relation (2), the attenuation coefficient μ is written as

$$\mu = \frac{1}{x}\ln\left[\frac{I_0}{I}\right]. \tag{2}$$

Since the intensities I and I_0 are proportional to the net count rate $C(t)$ with the same proportionality constant (same detection chain), then the ratio $\frac{I_0}{I}$ is equal to the ratio $\frac{C(t)_0}{C(t)} = e^{-\mu x}$.

The uncertainty $\Delta\mu$ on the measured values of the total attenuation coefficient μ is given from the application of the error propagation formula on relation (3)

$$\Delta\mu = \frac{1}{x}\left[\left(\frac{\Delta I_0}{I_0}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\ln\frac{I_0}{I}\right)^2 \cdot \left(\frac{\Delta x}{x}\right)^2\right]^{1/2}. \tag{3}$$

Attenuation is studied for the 122, 244, 344 and 661 KeV energies emitted by the point sources of ^{152}Eu and ^{137}Cs, respectively.

Experimentation. Though each type of ore is subdivided into three supposedly homogeneous samples of the same matrix and concentration of iron ore, three samples are taken from each category of materials from the free waste dumps of the deposit of Ouenza. They include: for rich iron ore: RI 1, RI 2 and RI 3; poor iron ore: PI 1, PI 2 and PI 3; marl: M1, M2 and M3 and for limestone: L1, L2 and L3.

The thickness of each sample is conditioned by the equipment used in the laboratory; the maximum thickness allowed during the measurement is 50 mm. The average thicknesses $\bar{X} \pm \sigma_x$ of the samples are presented in the Table 1.

Experimental device. Measurements of the various samples of free waste rock using the gamma spectrometer containing a NaI (Tl) detector 300 are used to determine linear attenuation coefficients. The signal obtained from the detector is amplified and recorded by a 16 k MCA Multi-Channel Analyzer. The measurement results are communicated to a computer equipped with Genie 2000 V3.2 spectrum processing software [10].

The experimental lab measuring stand is shown in Fig. 2. The linear attenuation is studied for the following energies: 122.78, 244, 344 and 661 KeV emitted by point sources europium and cesium: 152Eu (122.78, 244 and 344) KeV and 137Cs 661 KeV [11].

Results and Discussion. ***Chemical analysis results.*** The analysis results are shown in Table 2.

According to the obtained results, the content of the rich iron sample is 67.13 %, and of the poor iron is 32.55 %, while the CaO content remains high. For the marl sample, there is a high percentage of SiO_2 and Al_2O_3 in the sample which is respectively 58.62 and 15.75 %. Finally, for the limestone sample, the CaO content is 34.03 %.

X-ray Diffraction results. The obtained results on the X-ray diffraction spectra of rich iron, poor iron, marl and limestone samples are presented in Figs. 3–6.

From Fig. 3, the mineralogical composition of the original iron ore sample includes the following minerals: hematite, calcite and dolomite. It is noted that the peaks of hematite, calcite and dolomite, having a high intensity are well expressed, which makes their identifications easy and the crystallinity is associated with the majority of hematite in the sample; this is explained by the greater intensity of its peaks compared to other peaks.

Table 1

Variation of the thicknesses of the samples relative to the standard deviation

Samples	X1	X2	X3	X4	$\bar{X}$ *	σ_x*
RI 1	2.54	4.52	3.96	3.32	3.58	0.85
RI 2	2.1	3.06	3.6	4.32	3.27	0.93
RI 3	1.87	3.16	2.5	1.6	2.28	0.70
PI 1	1.81	2.46	2.97	2.99	2.55	0.55
PI 2	2.67	2.73	2.03	1.5	2.23	0.58
PI 3	2.9	2.58	2.08	1.81	2.34	0.49
L1	2.04	2.29	2.18	2.05	2.14	0.12
L2	2.01	1.85	1.05	2.22	1.78	0.51
L3	0.41	0.71	0.87	0.92	0.73	0.23
M1	2.39	1.81	2.33	1.72	2.06	0.35
M2	1.97	2.01	1.74	1.8	1.88	0.13
M3	2.42	2.54	3	3.21	2.79	0.37

* $\bar{X}$ – arithmetic mean; σ_x – average deviation to the mean value

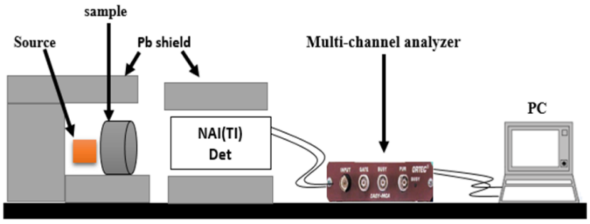


Fig. 2. Experimental Laboratory Measurement Stand

From Fig. 4, it is found that the mineralogical composition of the initial sample of the poor iron includes the following minerals: quartz, hematite and calcite. However, it is noted that the peaks of quartz and hematite, having a high intensity are well expressed, which makes their identifications easy.

From Fig. 5, it can be seen that the mineralogical composition of the original Marl sample consists of the following minerals: carbonate hydroxyl apatite, dolomite, goethite, quartz, and calcite. However, it is noted that the peaks of quartz and carbonate hydroxyl apatite, having a high intensity are well expressed, which makes their identifications easy.

From Fig. 6, it can be seen that the mineralogical composition of the limestone sample comprises the fol-

Table 2

X-ray Fluorescence Results of Samples

Samples	Content, %										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI
Ri	1.15	0.26	67.13	13.85	1.20	0.06	< 0.05	< 0.05	1.95	<0.05	16.35
Pi	21.65	12.13	32.55	6.14	1.20	0.06	<0.05	< 0.05	1.92	<0.05	22.67
Marl	58.62	15.75	6.58	10.38	< 0.05	<0.05	2.03	0.60	0.17	0.24	9.34
Limestone	25.78	0.26	4.73	34.03	0.88	0.13	1.73	0.28	0.16	0.16	25.82

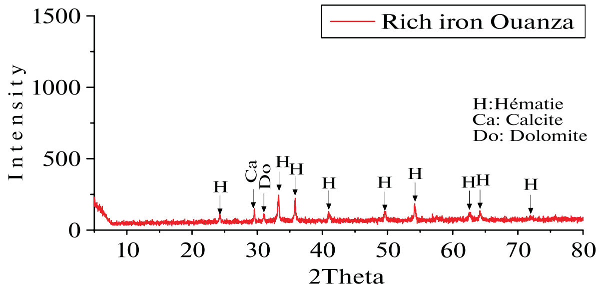


Fig. 3. X-ray diffraction spectrum of the initial sample of iron ore

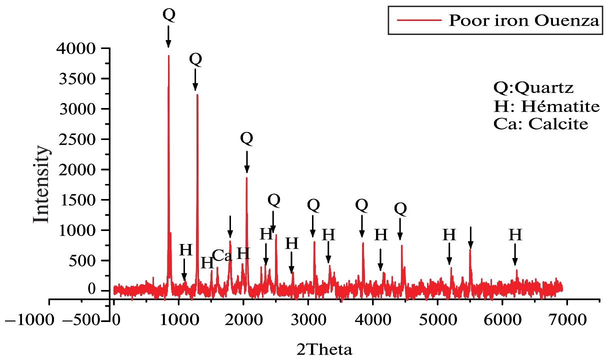


Fig. 4. X-ray Diffraction Spectrum of the Initial Sample of Poor Iron

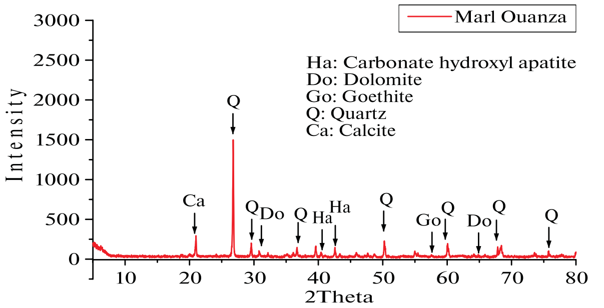


Fig. 5. X-ray diffraction spectrum of the initial sample of Marl

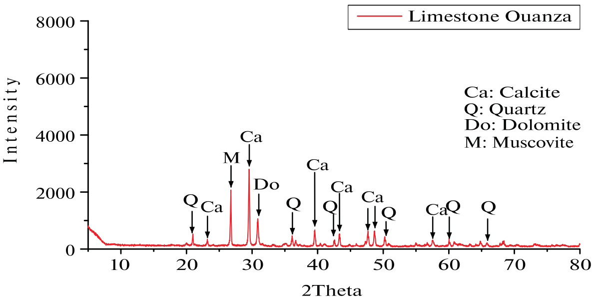


Fig. 6. X-ray diffraction spectrum of the initial limestone sample

lowing minerals: calcite, muscovite, quartz, and dolomite. However, it is noted that the peaks of calcite and muscovite, with high intensity are well expressed.

Results of the linear attenuation coefficient of waste rocks samples. The attenuation coefficient $\mu \pm \sigma_\mu$ for each sample has a given energy and is determined from expressions (1, 2) and is presented with the densities of each category in Table 3.

The values of the attenuation coefficient μ obtained from Table 3 make it possible to determine the weighted average $\bar{\mu} \pm \sigma_{\bar{\mu}}$ for each type of ore according to the following expressions.

$$\bar{\mu} = \frac{\sum_{i=1}^{3} \frac{\mu_i}{\sigma^2_{\mu_i}}}{\sum_{i=1}^{3} \frac{1}{\sigma^2_{\mu_i}}}; \qquad (4)$$

Table 3

Attenuation coefficient $\mu \pm \sigma_\mu$ of the waste rocks of the deposit of Ouenza

Samples	Density g/cm^3	Energies, KeV							
		121.78		244		344		661	
		M	σ_μ	μ	σ_μ	μ	σ_μ	μ	σ_μ
RI 1	4.9	0.446	0.106	0.202	0.0537	0.233	0.0558	0.206	0.0491
RI 2		0.450	0.129	0.247	0.0718	0.211	0.0608	0.143	0.0410
RI 3		0.556	0.170	0.448	0.138	0.323	0.0988	0.195	0.0597
PI 1	3.7	0.113	0.0246	0.0972	0.0264	0.281	0.0614	0.198	0.0432
PI 2		0.201	0.0527	0.0973	0.0289	0.132	0.0351	0.120	0.0315
PI 3		0.308	0.0646	0.294	0.0638	0.243	0.0512	0.229	0.0481
M1	2.7	0.141	0.0242	0.0733	0.0189	0.0815	0.0155	0.0794	0.0140
M2		0.179	0.0133	0.222	0.0233	0.177	0.0151	0.0863	0.0757
M3		0. 105	0.0147	0.107	0.0202	0.0942	0.0146	0.0876	0.0125
L1	2.8	0.270	0.0160	0.277	0.0246	0.250	0.0164	0.210	0.0126
L2		0.352	0.0101	0.289	0.0863	0.327	0.0946	0.228	0.0657
L3		0.275	0.0875	0.306	0.102	0.284	0.0913	0.229	0.0733

$$\sigma_{\bar{\mu}} = \left[\sum_{i=1}^{3}\frac{1}{\sigma^2_{\mu_i}}\right]^{-1/2}. \qquad (5)$$

According to the calculation results of the total linear attenuation coefficient obtained in Table 4, the highest coefficient value is of rich iron in 121.78 KeV among the others and for limestone in 244, 344 and 661 KeV. And the lowest coefficient is marl in the energy of 661 KeV.

The linear attenuation coefficients for the different types of free waste rock are measured with photon energies equivalent to 121.78, 244, 344 and 661 KeV. The obtained results are presented in Fig. 7.

It is clear from Fig. 7 that for a 121.78 KeV energy, a considérable difference between the coefficient of attenuation of rich iron ore and the other categories as a function of energy. The value μ for limestone is twice as much as other materials for 244 KeV energy. The two remaining products (marl and poor iron) can be separated last with energy of 344 KeV.

Influence InInfluence of the thickness of the sample on the attenuation coefficient. The fragmented sample thickness is one of the main factors acting on the γ-rays attenuation coefficient [12]; the values of $\bar{\mu}$ and the sum of $\bar{x}$ of each sample for each energy are represented in Fig. 8.

The attenuation coefficients as a function of the thickness for different energies are represented in Fig. 7, it can be seen that for an average thickness of 90 mm the values of the attenuation coefficient between the different materials are important.

For a Europium^{137} energy source, to separate the rich iron ore from other categories, we use energy of 121.78 KeV corresponding to $\mu = 0.45$ cm^2/g. In the second stage of separation of limestone from other materials for the same energy source with the same thickness is used with the energy of 244 KeV corresponding to $\mu = 0.25$ cm^2/g. Finally to separate the poor iron ore from the marl, 344 KeV energy is used corresponding to $\mu = 0.195$ cm^2/g.

Influence of iron content on the attenuation coefficient. The iron ore content has a considerable impact on the degree of absorption of γ-rays; this is the main factor that influences the attenuation coefficient of the γ-rays [13]. The values of $\bar{\mu}$ and the contents between 32 and 67 % of each sample for each energy is represented in Fig. 9.

From Fig. 9 for 121.78 KeV energy with an attenuation coefficient equal to 0.45 cm^2/g, it can be seen that a 65 % iron concentrate can be obtained at the first separation stage. It is similar for the poor iron ore, so from 344 KeV energy with an attenuation coefficient equal to 0.195 cm²/g, a concentrate of content equal to 37.5 % can be obtained at the second separation stage. The latter will undergo a deep subsequent treatment after grinding to meet the metallurgical requirements.

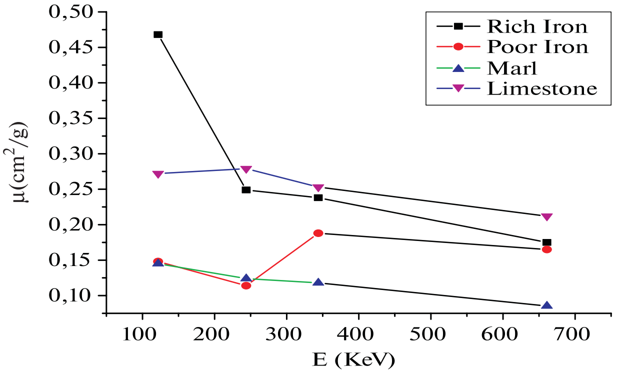


Fig. 7. Variation of mass attenuation coefficient as a function of punctual energy

Therefore, the radiometric sorting method by gamma ray absorption can be applied to the waste rocks of Ouenza, the proposed steps for the separation of waste rocks is presented in Fig. 10.

Conclusion.

1. Ouenza mine produces about 1.8 million tons of waste rocks annually; the management of waste rock is an economic and environmental challenge.

2. According to the mineralogical composition, four types of categories make up the waste rocks, these are rich iron ore (RI); poor iron ores (PI); Marne and Limestone.

3. Attenuation is studied for the energies 122, 244, 344 and 661 KeV emitted by the point sources of ^{152}Eu and ^{137}Cs, respectively.

4. The thickness of each sample is conditioned by the equipment used at the laboratory; the maximum thickness allowed during the measurement is 90 mm.

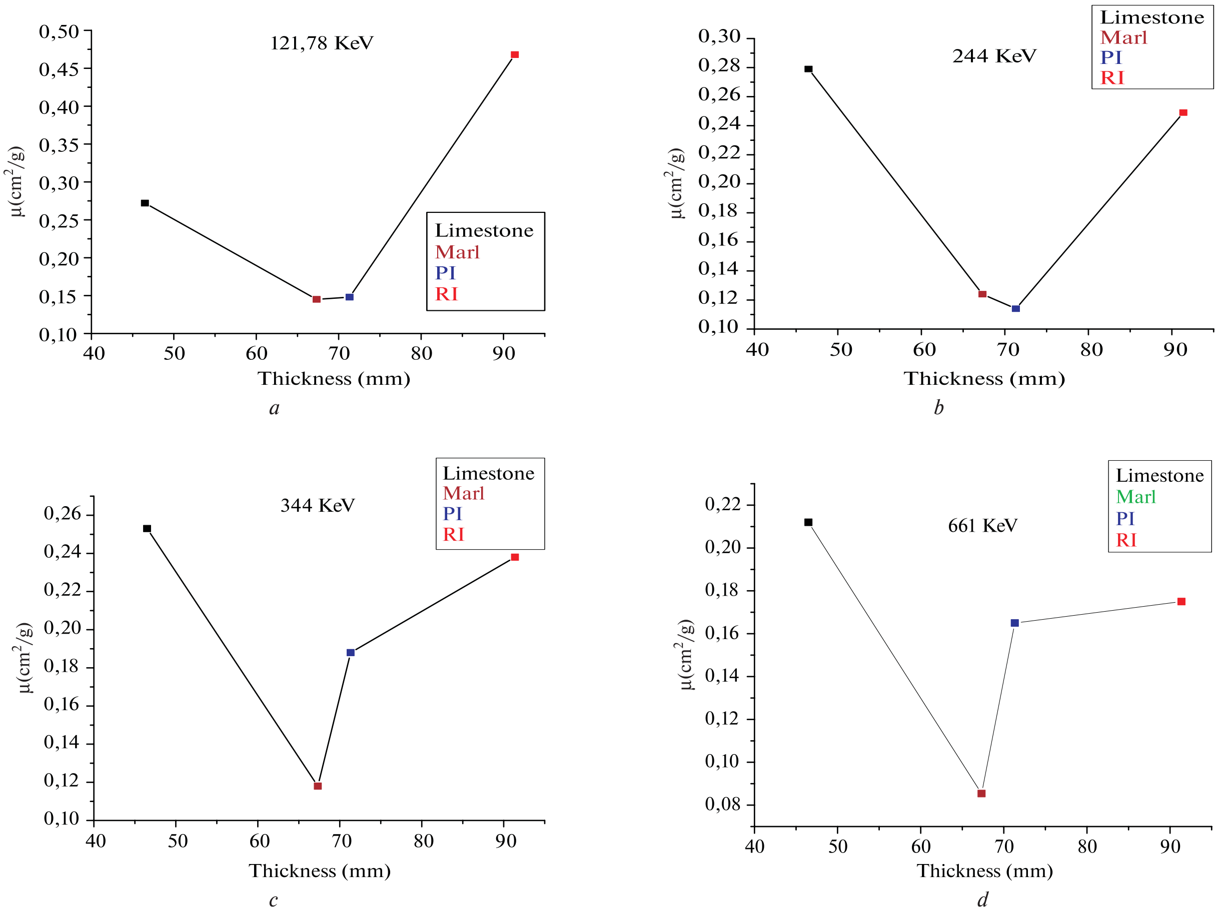
5. The measurements of the various samples of the free waste materials using the gamma spectrometer containing a NaI (Tl) detector 300 is used to determine linear attenuation coefficients.

6. The attenuation coefficients as a function of the thickness for different energies, we see that for an average thickness of 90 mm, the values of the attenuation coefficient between the different materials are important.

Table 4

Calculated values of the total linear attenuation coefficient

Samples	Rich iron		Poor iron		Marl		Limestone	
Energies (KeV)	$\bar{\mu}$	$\sigma_{\bar{\mu}}$	$\bar{\mu}$	$\sigma_{\bar{\mu}}$	$\bar{\mu}$	$\sigma_{\bar{\mu}}$	$\bar{\mu}$	$\sigma_{\bar{\mu}}$
121.78	0.468	0.0738	0.148	0.0211	0.145	0.00913	0.272	0.0155
244	0.249	0.0410	0.114	0.0187	0.124	0.0119	0.279	0.0230
344	0.238	0.0380	0.188	0.0263	0.118	0.00868	0.253	0.0159
661	0.175	0.0278	0.165	0.0225	0.0854	0.00588	0.212	0.0122



a *b* *c* *d*

Fig. 8. Evaluation of μ *as a function of the thickness for each energy:*

a — the thickness according to the energy 121.78 KeV; b — the thickness according to the energy 244 KeV; c — the thickness according to the energy 344 KeV; d — the thickness according to the energy 661 KeV

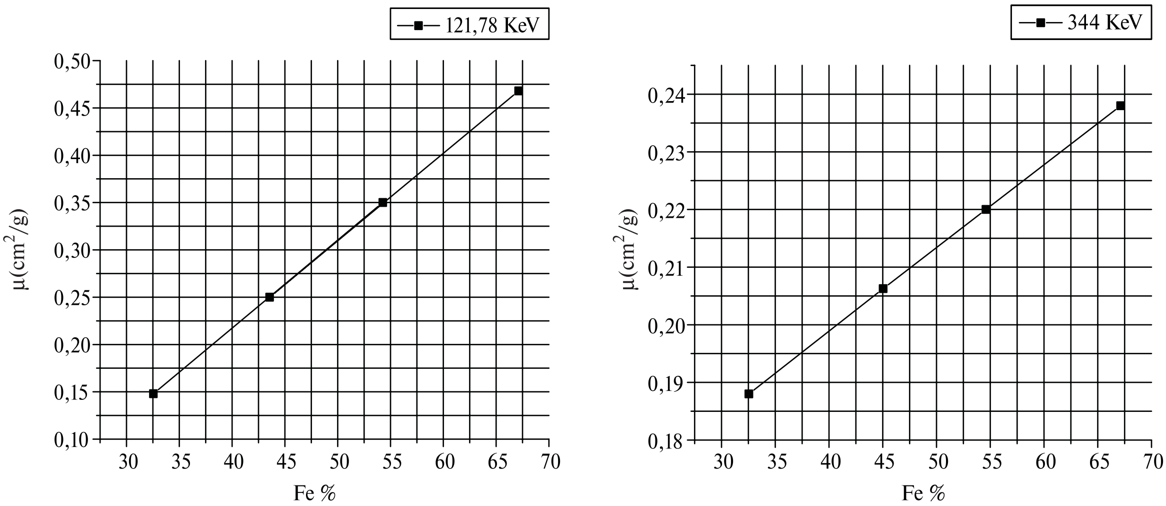


Fig. 9. Influence of the iron content on the attenuation coefficient μ *for different energy*

7. For 121.78 KeV energy with an attenuation coefficient equal to 0.45 cm^2/g, it is possible to obtain a 65 % iron concentrate at the first separation stage. For lean iron ore, with 344 KeV energy an attenuation coefficient equal to 0.195 cm^2/g, a concentrate with a content equal to 37.5 % is obtained at the second separation stage.

8. The method for radiometric sorting by gamma absorption can be applied at the level of the company of Ouenza.

Acknowledgments.

This article is realized in collaboration with the Laboratory for the Valorization of Mining Resources and Environment, University Badji-Mokhtar Annaba, Al-

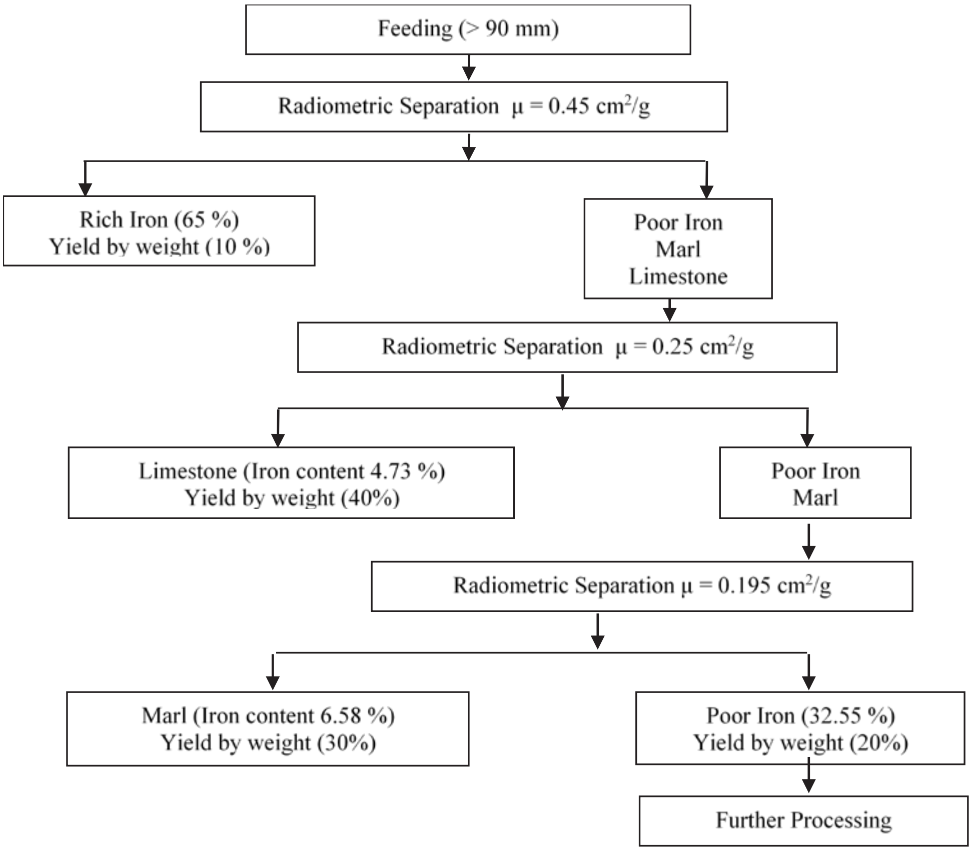


Fig. 10. Scheme of radiometric separation proposed for mining wastes from Ouenza mine

geria. We would like also to express our thanks to the Laboratory of the Nuclear Research Center of Algiers for their assistance to carry out the present research work.

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Радіометрична сортувальна техніка для видобутку корисних копалин з відвалів рудника Уенза (Алжир)

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Мета. Дане дослідження присвячене вивченню характеристики й підвищення цінності породних відвалів рудника Уенза за допомогою фізичних методів. Хімічний і мінералогічний аналізи, проведені із трьома категоріями порід, узятих із відвалів, дозволяють виділити три категорії матеріалів на всіх місцях відвалу, а саме: червоний залізняк, що становить 30 %, вапняк із вмістом глини – 30 % і вапняк – 40 %. Це призводить до проблем управління й розміщення порід на поверхні. Метою дослідження є пошук способів видалення порожніх порід з відвалів рудників Уенза.

Методика. Проведено бібліографічне дослідження щодо порожніх порід. Для опису цих пустих порід використовується визначення характеристик за допомогою дифракційного рентгенівського аналізу різних категорій і вихідних зразків, а також хімічний аналіз трьох категорій матеріалів із відвалів рудника Уенза за допомогою FX (рентгенівська флуоресценція). Були застосовані тести для вимірювання масового коефіцієнта ослаблення зразків порожніх порід, переводячи пучок гамма-випромінювання в тонку геометрію. Загасання вивчалося для енергій 122, 244, 344 і 661 KeV, що випромінювалися точковими джерелами ^{152}Eu та ^{137}Cs відповідно.

Результати. Різні зразки сировини проаналізовані за допомогою дифракційного рентгенівського аналізу та FX. Отримані результати показують, що мінералогічний склад включає кальцит, кварц і червоний залізняк. Кращі результати досягаються за наступних параметрів: товщина зразків становить від 80 до 90 мм, зразок захоплює весь пучок гамма-випромінювання та значення енергії становить від 122 до 661 KeV, що істотно сприяє радіометричному відділенню порожніх порід на руднику Уенза, Алжир.

Наукова новизна. Полягає в можливості застосування радіометричного методу. Цей процес допускає виборчу розробку породних відвалів рудника Уенза, з використанням гамма-випромінювання різних енергій, з урахуванням товщини зразків і вмісту в них заліза. Прийом поділу простий і економічний, не вимагає капіталовкладень у встановлення великого промислового обладнання.

Практична значимість. Залізна руда має великий попит на світовому ринку. Однак потрібне сортування та оцінка породних відвалів, щоб продукт був комерційно вигідним. Залізна руда, що оброблена запропонованим способом, відповідає промисловим вимогам і міжнародним стандартам, зокрема, у сталеливарній промисловості; вміст заліза досягає 67.13 %.

Ключові слова: *управління порожніми породами, радіометричний метод, гамма-випромінювання, залізорудне родовище Уенза*

Радиометрическая сортировочная техника для добычи полезных ископаемых из отвалов рудника Уэнза (Алжир)

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Цель. Данное исследование посвящено изучению характеристики и повышения ценности породных отвалов рудника Уэнза с помощью физических методов. Химический и минералогический анализы, проведенные с тремя категориями пород, взятых из отвалов, позволяют выделить три категории материалов на всех местах отвала, а именно: красный железняк, который составляет 30 %, известняк с содержанием глины – 30 % и известняк – 40 %. Это приводит к проблемам управления и размещения пород на поверхности. Целью исследования является поиск способов удаления пустых пород из отвалов рудников Уэнза.

Методика. Проведено библиографическое исследование касательно пустых пород. Для описания этих пустых пород использовано определение характеристик с помощью дифракционного рентгеновского анализа разных категорий и исходных образцов, а также химический анализ трех категорий материалов из отвалов рудника Уэнза с помощью FX (рентгеновская флуоресценция). Были использованы тесты для измерения массового коэффициента ослабления образцов пустых пород, переводя пучок гамма-излучения в тонкую геометрию. Затухание изучалось для энергий 122, 244, 344 и 661 KeV, излученных точечными источниками ^{152}Eu и ^{137}Cs соответственно.

Результаты. Различные образцы сырья проанализированы с помощью дифракционного рентгеновского анализа и FX. Полученные результаты показывают, что минералогический состав включает кальцит, кварц и красный железняк. Лучшие результаты достигаются при следующих параметрах: толщина образцов составляет от 80 до 90 мм, образец захватывает весь пучок гамма-излучения и значение энергии составляет от 122 до 661 KeV, что существенно способствует радиометрическому отделению пустых пород на руднике Уэнза, Алжир.

Научная новизна. Состоит в возможности применения радиометрического метода. Этот процесс допускает избирательную разработку породных отвалов рудника Уэнза, с использованием гамма-излучения различных энергий, с учетом толщины образцов и содержания в них железа. Прием разделения прост и экономичен, не требует капиталовложений в установление крупного промышленного оборудования.

Практическая значимость. Железная руда пользуется большим спросом на мировом рынке. Однако требуется сортировка и оценка породных отвалов, чтобы продукт был коммерчески выгодным. Железная руда, обработанная предложенным способом, соответствует промышленным требованиям и международным стандартам, в частности, в сталелитейной промышленности; содержание железа достигает 67.13 %.

Ключевые слова: *управление пустыми породами, радиометрический метод, гамма-излучение, железорудное месторождение Уэнза*

Рекомендовано до публікації Ахен Бухеджа. Дата надходження рукопису 18.08.17.