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Neutron Activation Analysis of Saudi Hematite and Phosphate Samples Using the ^{241}Am-Be Neutron Irradiation Facility

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ABSTRACT. The elemental analysis of hematite and phosphate Saudi ore samples have been done by means of the instrumental neutron activation analysis technique (INAA).

The samples and the standards used were irradiated in a thermal neutron flux of 1.9×10^3 n/cm^2·s using 5Ci ^{241}Am-Be irradiation facility, which was designed for this purpose. The gamma-ray spectra were collected by means of the well calibrated hyper pure germanium detection system.

More than 35 gamma ray lines have appeared in the irradiated hematite ore samples spectra and they were belonging to the elements of Al, K, Ti, Mn, Fe, As, Eu and Ra. The concentration percentage value of Mn in hematite has been evaluated as 0.332 ± 0.013%.

In phosphate ore sample spectra more than 30 gamma-ray lines have been identified which were belonging to: Na, K, Sc, Fe, La, Ra, Th and U elements. The Na concentration percentage value in phosphate ore has been determined to be 9.17 ± 0.33%.

Introduction

Modern technology requires great progress towards sensitive methods of analysis. For certain purposes, high purity materials are demanded, where the level of other contaminates must be well known. The conventional methods of chemical analysis can not usually be applied for the determination of most of these elements. Activation analysis is one of the most sensitive methods of analysis, and has been developed parallel to nuclear energy progress, during the last four decades.

Thermal neutrons have been more widely used for activation analysis than any other type of particles. This is mainly due to the high cross-section of most nuclei for thermal neutrons and the availability of higher neutron flux at nuclear reactors. The details of using fast neutrons or charged particles in activation analysis are discussed by Bowen and Gibbons[1]. A knowledge of the nuclear properties of the elements is essential to activation analysis, such properties are available in "Charts of the nuclides"[2,3] and in a number of compilations[4-7].

The application of gamma-ray spectrometry using solid state detectors in activation analysis[8] offers certain advantages over the chemical separation method with respect to specifity and avoidance of contamination. In addition, it makes analysis more rapid and allowing isotopes with shorter half-lives, to be determined. Fully automated computer based activation analysis was used to examine and measure the photopeaks in a gamma-ray spectrum, and to identify the radioisotopes and calculate their amount present[9-11].

The increasing need for improved advanced techniques for the non-destructive multielement analysis of complex samples has led to the development of high yield isotope neutron sources with several neutron analysis techniques.

The theory of activation analysis, technique used facilities required, sensitivity, reproducibility, sources of errors, and applications in the various phases of science and technology have been discussed in details in many of scientific books[8-18].

The main aim of this work was attained through the studies on the neutron activation analysis for hematite and phosphate Saudi ore samples. The $5Ci^{241}$Am-Be irradiation facility as well as the hyper pure germanium gamma-ray detection system was used.

Experimental Set-Up

Neutron Irradiation Facility

The $5Ci^{241}$Am-Be isotopic neutron source facility was used for irradiation of the samples investigated in this work. The irradiation facility was designed and constructed for the purpose of irradiating the samples as well as for storing the neutron source. It contains a cylinder of iron of 0.2 cm thickness with height of 100 cm and diameter of 80 cm, filled with borated paraffin wax. The iron cylinder is surrounded by a sheath of Pb of 0.30 cm thickness.

The $5Ci^{241}$Am-Be neutron source is positioned at the centre of this cylinder where the samples could be irradiated through a vertical hole of 10 cm diameter and 40 cm height. Four horizontal holes were located at the centre of the iron cylinder which are used as horizontal channels for irradiation of the samples as well. The diameter of each channel was about 3 cm with horizontal depth of 40 cm. These horizontal channels are designed to see in a direct form the neutron source positioned in the centre or the paraffin cylinder. Fig. (1) shows a sketch of the 5Ci^{241}Am-Be neutron source irradiation facility.

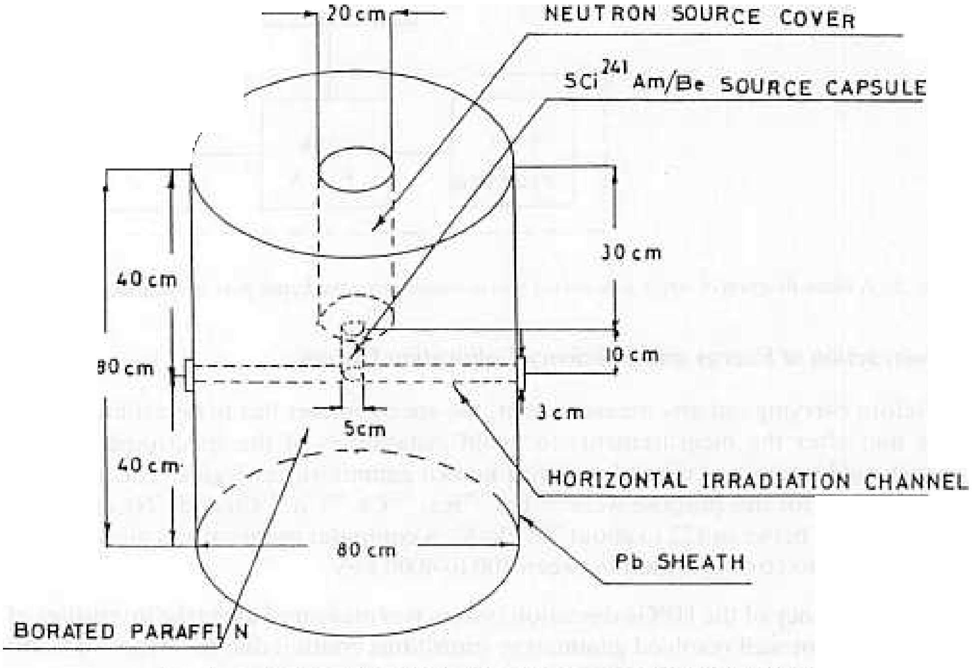


FIG. 1. A sketch of the 5Ci^{241}Am/Be neutron source irradiation facility

In order to irradiate samples in a powder form, a polyethelene container was used and was positioned in the vertical hole, close to the neutron source as shown in Fig. (1). The whole assembly is located on a movable metallic container. The irradiated samples are transferred to the measuring position by means of a mechanical hand of 200 cm long arm in order to avoid the irradiation hazards.

The Gamma-Ray Spectroscopy System

A block diagram of the system used in gamma-ray measurements for the current work is as shown in Fig. (2). A 20% hyper pure germanium detector (HPGe with 20% efficiency) was used for gamma-ray detection. It has an energy resolution of about 2.2 keV for the 1332 keV of ^{60}Co gamma-ray line. A sensitive preamplifier unit is mounted next to the detector to reduce the effect of the capacitance loading and improving the signal to noise ratio.

The output pulses of the preamplifier is passed to a linear amplifier. The unipolar output of this linear amplifier was fed as an input to the 4096 multi-channel analyzer. The output is printed out as the number of counts for each channel. The gamma-ray spectra obtained for each sample are plotted manually.

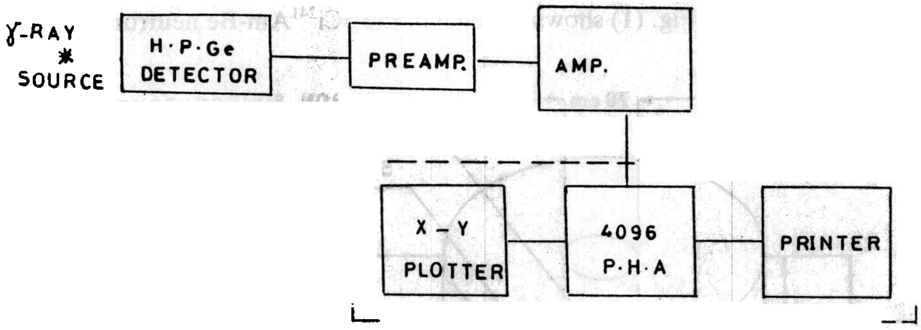


FIG. 2. A block diagram of single gamma-ray spectrometer using the hyper pure germanium detector.

Construction of Energy and Efficiency Calibration Curves

Before carrying out any measurement, the spectrometer has to be calibrated before and after the measurements to avoid instabilities of the spectrometer. The energy calibration was carried out with known gamma-ray energies. The standard sources used for this purpose were ^{228}Th, ^{226}Ra, ^{137}Cs, ^{60}Co, ^{57}Co and ^{22}Na extended energy range between 122 to about 2614 keV. A computer program was prepared for this purpose to cover a region between 100 to 4000 keV.

The efficiency of the HPGe detection system was measured using the intensities of some different well resolved gamma-ray transitions emitted due to ^{182}Ta, ^{160}Tb and ^{226}Ra sources as listed in Table (1).

The sources were placed at a distance of about 3 cm apart from the detector.

TABLE Gamma-ray energies of standard sources used for efficiency calibration.

Source	Eγ keV
^{226}Ra and its daughters	186.210
	241.981
	295.213
	351.921
	609.312
	768.356
	1120.287
	1238.710
	1377.669
	1509.228
	1729.595
	1847.420
	2118.551
	2204.215
	2447.860

Source	Eγ keV
^{182}Ta	100.1
	152.4
	179.5
	264.0
^{160}Tb	197.0
	197.0
	299.0
	392.0
	682.0
	765.0
	879.0
	1102.7
	1177.0
	1272.0

The absolute full energy peak efficiency curve of the HPGe detection system used is shown in Fig. (3). The relative error is estimated to be within ±5% over the whole range of the curve.

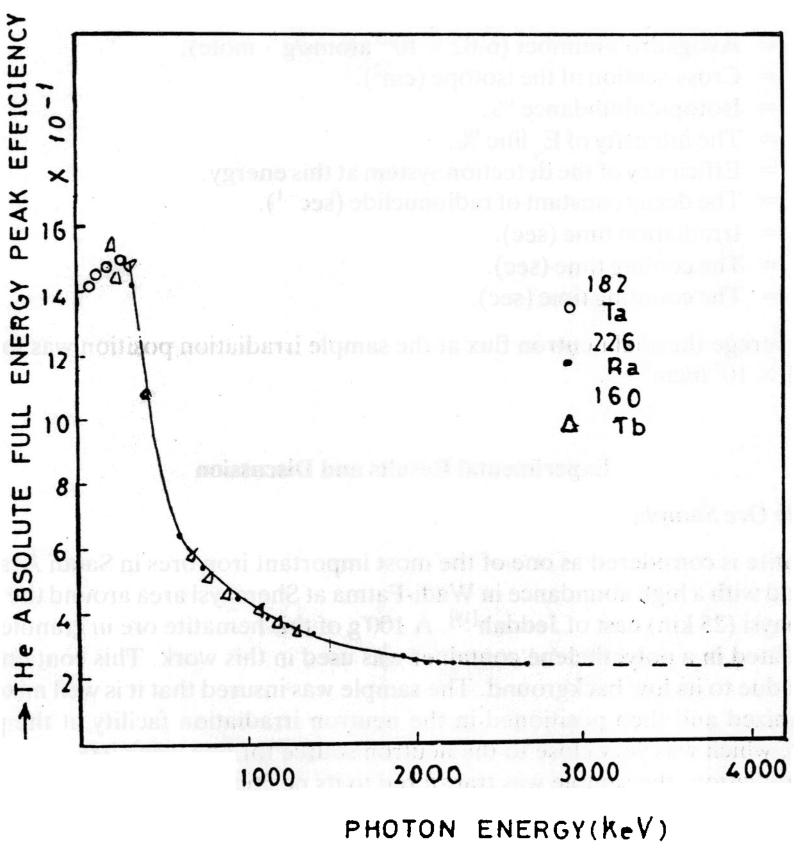


FIG. 3. The absolute full energy peak efficiency for the hyper pure germanium detection system.

Neutron Flux Determination

The foil activation method was used for thermal neutron flux measurements in this work. The ^{197}Au gold isotope foil of about 100% abundance and thermal neutron capture cross-section of 98.8 b was used. The strong gamma-ray line appeared at 411.8 keV due to the decay of the product isotope ^{198}Au to ^{198}Hg was used to determine the activity of this reaction, the following equation was applied to calculate the thermal neutron flux :

$$\phi = \frac{A(t) \cdot M(i)}{m_o \cdot N_L \cdot \sigma_i \cdot \theta \cdot I_\omega \cdot \varepsilon \cdot (1 - e^{-\lambda t})\,(e^{-\lambda t2} - e^{-\lambda t1})} \qquad (1)$$

where :

ϕ = Neutron flux ($n/cm^2 \cdot sec$).
$A(t)$ = The activity γ/sec.
$M(i)$ = Atomic weight of the target element (g).
m_o = The weight of the element (g).
N_L = Avogadro's number (6.02×10^{23} atoms/g · mole).
σ_i = Cross-section of the isotope (cm^2).
θ = Isotopic abundance %.
I_γ = The intensity of E_γ line %.
ε = Efficiency of the detection system at this energy.
λ = The decay constant of radionuclide (sec^{-1}).
t = Irradiation time (sec).
t_1 = The cooling time (sec).
t_2 = The counting time (sec).

The average thermal neutron flux at the sample irradiation position was found to be 1.991×10^3 $n/cm^2 \cdot s$.

Experimental Results and Discussion

Hematite Ore Sample

Hematite is considered as one of the most important iron ores in Saudi Arabia. It was found with a high abundance in Wadi-Fatma at Shemaysi area around the village of Shemaysi (25 km) east of Jeddah[19]. A 100 g of this hematite ore in granules form encapsulated in a polyethelene container was used in this work. This container was choosen due to its low background. The sample was insured that it is well mixed and homogenized and then positioned in the neutron irradiation facility at the proper position, which was very close to the neutron source for one week irradiation time. After irradiation, the sample was transfered to its position at the detection system.

Gamma-Ray Spectrum Measurements and Qualitative Analysis of Hematite Ore Sample

The gamma-ray spectrum of hematite ore sample has been collected by means of the HPGe detection system for 3600 s. and plotted as shown in Fig. (4) up to 2500 keV. A total of 35 gamma-ray lines have been identified in the spectrum. It was found that the tables mentioned in references[20-23] were very useful in identification of each element belonging to its characterized gamma-ray lines.

The half-life of each isotope, its abundance as well as the intensity of each gamma-ray line were the main factors used to identify each element in the sample under investigation.

More than one measuring run for the gamma-ray spectrum was found very useful to identify the exact related element with high accuracy. Different time intervals between each run are needed depending on the half-life time of the interested element.

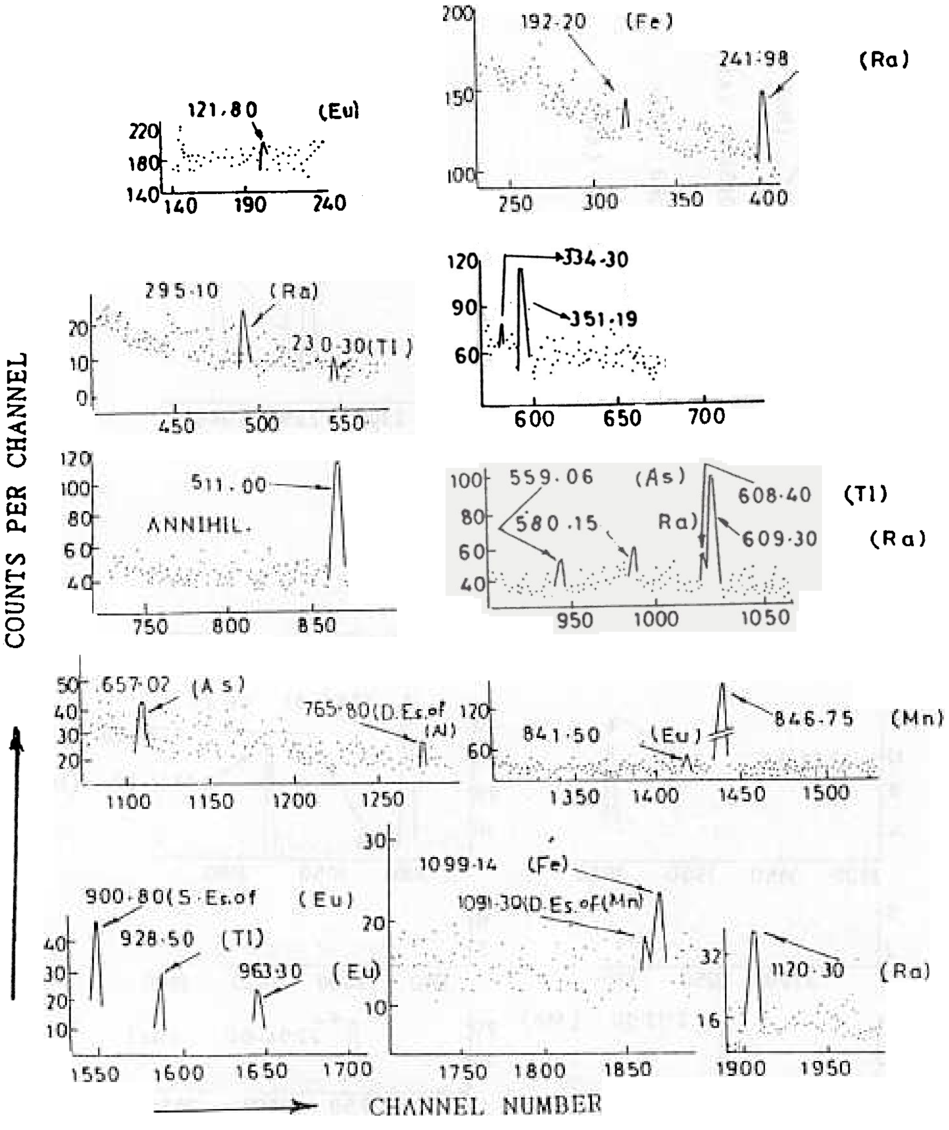


FIG. 4. The gamma-ray spectrum of hematite ore sample collected by the hyper pure germanium detection system for 3600 seconds. (Energy up to 1200 keV).

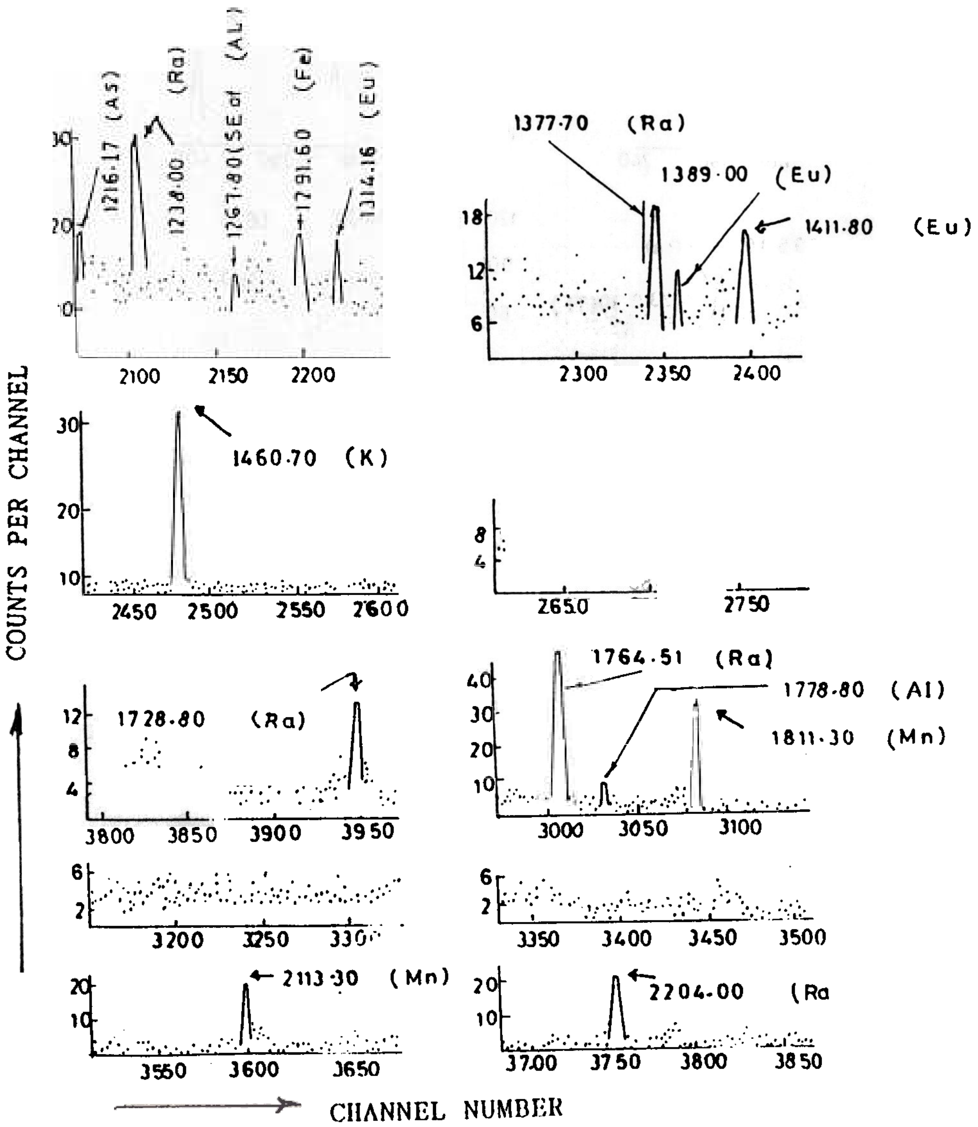


FIG. 4. (cont.) Energy from 1200 keV up to 2500 keV.

It was found that the 35 gamma-ray lines appeared in the gamma-ray spectrum of the irradiated hematite ore sample were belonging to the following 8 elements; (Al), (K), (Ti), (Fe), (As), (Eu), (Ra) and its daughters, as listed in Table (2).

TABLE 2. The gamma-ray lines appeared due to different isotopes of the elemental constituents of the irradiated hematite ore sample with ^{241}Am-Be neutron source. The isotopic abundance, half-life ($\tau_{1/2}$) and the neutron capture cross-section are presented.

Element	Product Isotope	Method of production	Isotopic %	($\tau_{1/2}$)	σ Barn	Gamma-ray energies Obtained in this work in (keV)
A1	^{28}A1	^{27}A1 (n · γ) ^{28}A1	100	2.3 min	0.23	1778.80 1276.80 (S.E.) 765.80 (D.E.)
K	^{40}K	Natural decay chain	–	1.27 × 10y		1460.70
Ti	^{51}Ti	^{50}Ti (n · γ) ^{51}Ti	53	5.7 min	0.179	320.30, 608.40 928.50
Mn	^{56}Mn	^{55}Mn (n · γ) ^{56}Mn	100	3.5 hr	13.3	846.75 1811.30, 789.30 (D.E.) 2113.30, 1091.30 (D.E.)
Fe	^{59}Fe	^{58}Fe (n · γ) ^{59}Fe	0.31	4.6 d	1.15	192.20, 1099.14 1291.60
As	^{76}As	^{75}As (n · γ) ^{76}As	100	26.32 hr	4.3	559.06, 657.02 1216.17
Eu	^{152}Eu	^{151}Eu (n · γ) ^{152}Eu	47.8	9.3 hr	3300	121.80, 344.30, 841.50, 963.30 1314.61, 1389.00 1411.80, 900.80 (S.E.)
Ra	^{226}Ra	Natural decay chain	–	1600 y		241.98, 295.10, 351.19, 580.15, 609.30, 1120.30 1238.00, 1377.70, 1728.80, 1764.51 2204.00

Evaluation of Manganese Percentage in Hematite Ore Sample

Manganese element has an isotope of ^{55}Mn of 100% abundance, with a thermal neutron cross-section of ~ 13.3b.

Each gamma-ray line was used to determine the concentration percentage value of manganese using the following two methods: The first method depends mainly on the neutron flux and the efficiency of the system used which could be summarized as follows :

The net peak area for each gamma-ray line is calculated and the activity of the irradiated sample could be obtained. Using the following equation, which is extracted from equation (1) :

$$m_{e} = \frac{A(t) \cdot M(i)}{\phi \cdot N_{i} \cdot \sigma_{i} \cdot \theta \cdot I \cdot \varepsilon \cdot (1 - e^{-\lambda t})\,(e^{-\lambda t2} - e^{-\lambda t1})} \quad (2)$$

the mass of the element (m_e) could be estimated using the values of ϕ, and ε. The data is obtained for a 100 g of hematite ore irradiated sample.

The average corrected percentage concentration value of Mn in hematite ore sample is obtained as 0.332 ± 0.013%.

The second method depends on the concentration values of some standard samples of Mn and the net peak area of the selected gamma-ray lines, which called, the sensitivity curves as follows :

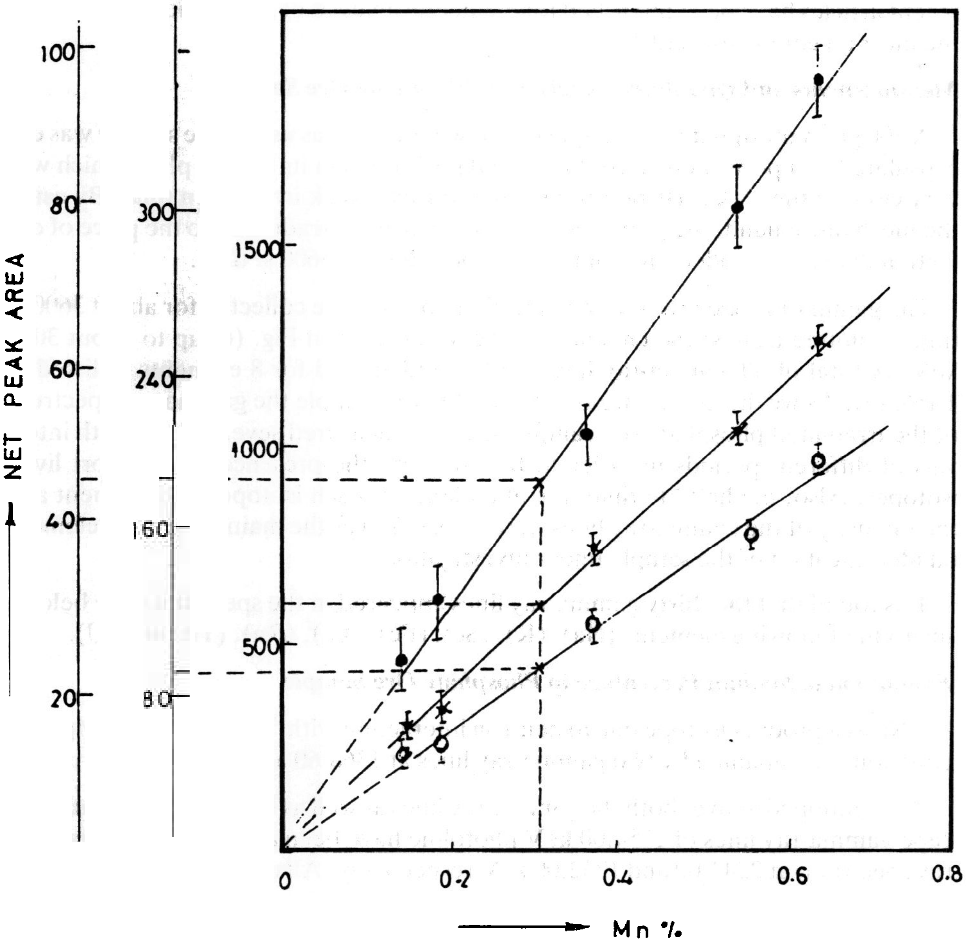
Five samples of manganese sulphate mixed with pure sand to make 5 concentration values of manganese at: 0.15, 0.19, 0.37, 0.55 and 0.64 percent were used to construct the sensitivity curves of manganese for each gamma-ray line mentioned above, as follows :

Equal amounts of the mixed samples were encapsulated in polyethelene capsules and irradiated together with a sample of pure sand which has about zero manganese concentration value as well as a sample of hematite only. After irradiation of about 10 days time, each sample was transferred to the detection position in front of the HPGe detector. The gamma-ray spectrum for each sample had been collected for 900 s. The net peak areas for manganese gamma-ray lines at 846.75, 1811.30 and 2113.30 keV have been calculated, and plotted against the concentration values as shown in Fig. (5). The net peak area of the same gamma-ray lines using the hematite ore sample which irradiated under the same conditions have been calculated and then the concentration percentage values could be extracted from the sensitivity curves.

The obtained values were as listed in Table (3). The average manganese percentage concentration value in hematite ore sample was found to be 0.325 ± 0.056%. This value was very close to that value obtained by the above method of (of 0.332 ± 0.013%), which is in good agreement with that obtained by the prompt gamma-ray technique mentioned in refs.[24, and 25].

Phosphate Ore Sample

Phosphate ores are of industrial importance, and more knowledge is needed on their qualitative and quantitative analysis. In Saudi Arabia, phosphate ore is found in the north borders in two main zones of Taif and Thinaiat up till Skaka.



IG. 5. Calibration curves for Mn determination in hematite ore sample using the gamma-ray lines at: 846.75 keV (✱), 1811.30 keV (○), and 2113.3 keV (●).

TABLE 3. The percentage concentration value of Mn element in hematite ore sample obtained by using the sensitivity curves at 846.75, 1811.00 and 2113.00 keV gamma-ray lines. (The data is corrected for background).

γ - Ray line	The percentage concentration value obtained for Mn	The average value of the present work	Ref. (24) and (25)
846.75 1811.30 2113.30	0.320 ± 0.062 0.330 ± 0.053 0.325 ± 0.054	0.325 ± 0.056 %	0.42 ± 0.02

The local phosphate sample under investigation was taken from Alsanam area. No recent articles have been published for elemental analysis of Saudi phosphate except the most recent one of ref.[24].

Measurements and Qualitative Analysis of Phosphate Ore Sample

A 100 gram phosphate ore sample in a powder form was used. The sample was encapsulated in a polyethelene container and positioned in its proper place which was very close to the ^{241}Am-Be neutron source, for one week irradiation time. By using the mechanical hand, the sample was transferred after irradiation to the place of detection in order to collect the gamma-ray spectrum for 3600 s. time.

The gamma-ray spectrum of the phosphate ore sample collected for about 3600 s. time is plotted against the channel numbers as shown in Fig. (6) up to about 3000 keV. A total of 30 gamma-ray lines could be identified for 8 elements as listed in Table (4). As we did before in case of hematite ore sample the gamma-ray spectrum of the irradiated phosphate ore sample has been measured several times with intervals of different periods in order to be sure with the presence of the short lived isotopes. Also, the half life time, the abundance of each isotope in its element and the intensity of the gamma-ray lines were considered as the main factors for elemental identification of the sample under investigation.

It is found that the thirty gamma-ray lines appeared in the spectrum were belonging to the following elements (Na), (K), (Sc), (Fe), (La), (Ra), (Th) and (U).

Evaluation of Sodium Percentage in Phosphate Ore Sample

^{24}Na as a product isotope due to neutron interaction with ^{23}Na, decay to ^{24}Mg by ß-emission accompanied by two gamma-ray lines at 1368.60 and 2754.00 keV.

As mentioned above, both the gamma-ray lines as well as the single and double escape gamma-ray lines of 2754.00 keV photoline have been appeared in the gamma-ray spectrum, at 2243.00 and 1732.00 keV respectively. All of these gamma-ray lines are used to determine the concentration percentage value of sodium in phosphate ore sample by the same two methods mentioned in case of hematite ore sample. The first method depends on the measured neutron flux and the efficiency of the detection system where Equation (2) was applied and the activity of a 100 g of the phosphate ore sample at the photo gamma-ray lines of 1368.60 and 2754.00 keV were used as well. The average corrected value of sodium concentration percentage in phosphate ore sample was obtained as: (8.850 ± 0.125%).

The second method which depends mainly on the sensitivity curves, was applied by irradiating five samples of mixed NaCl with pure sand as a matrix material. In this method, the five concentration values of sodium at 6.1, 11.3, 17.0, 22.7 and 39.7% in addition to the zero concentration value using the pure sand only and a sample of phosphate ore are used. A 100 g of each sample was encapsulated in a polyethelene container. The seven containers were irradiated for one week time. After irradiation, the gamma-ray spectrum of each sample was collected by the hyper pure germanium detection system under the same conditions.

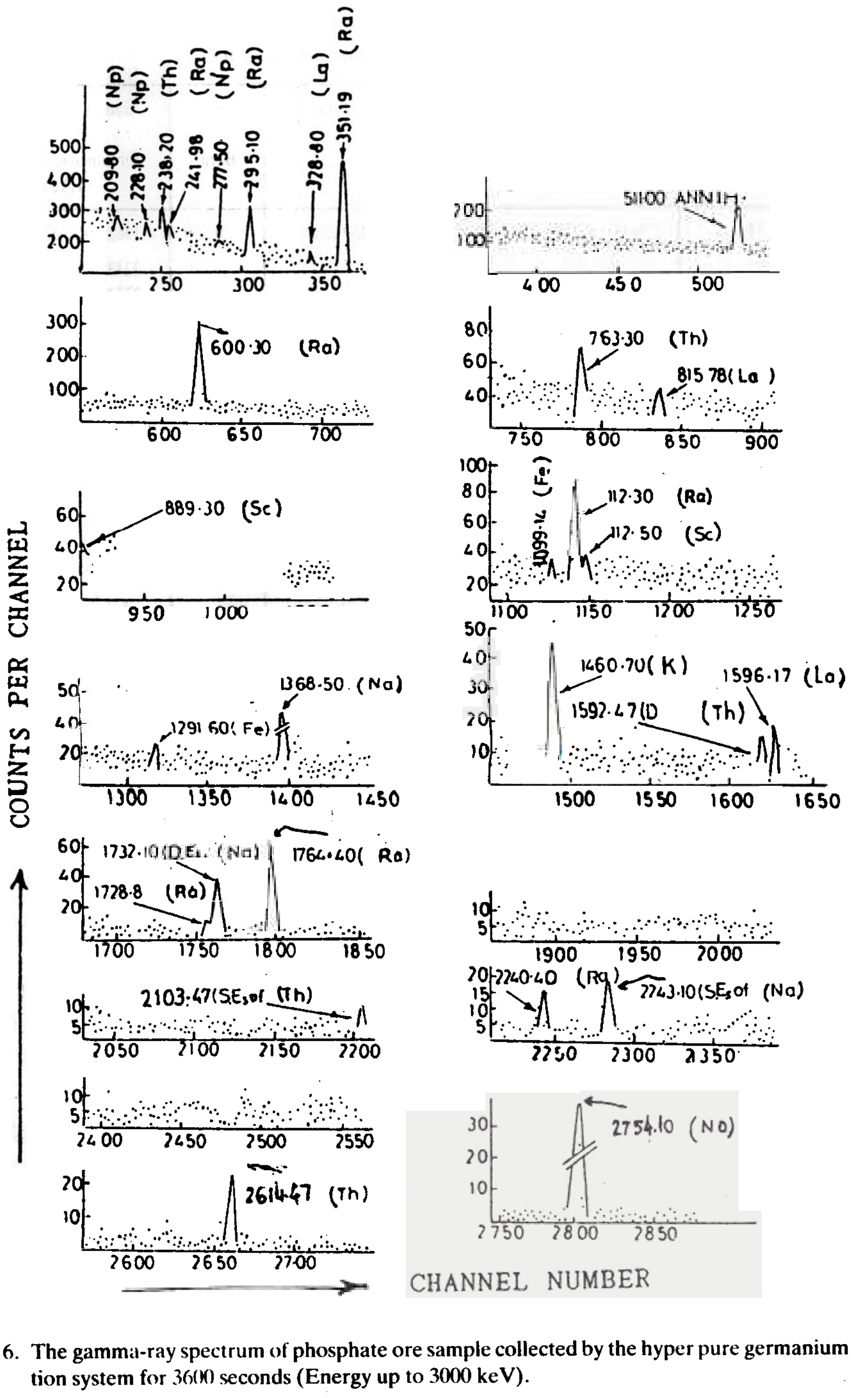


FIG. 6. The gamma-ray spectrum of phosphate ore sample collected by the hyper pure germanium detection system for 3600 seconds (Energy up to 3000 keV).

TABLE 4. The gamma-ray lines appeared due to different isotopes of the elemental constituents of the irradiated phosphate ore sample with ^{241}Am-Be neutron source. The isotopic abundance, half-life ($\tau_{1/2}$) and the neutron capture cross-section are presented.

Element	Product Isotope	Method of production	Isotopic %	($\tau_{1/2}$)	σ Barn	Gamma-ray energies Obtained in this work in (keV)
Na	^{24}Na	^{23}Na (n · γ) ^{24}Na	100	15.02 hr	0.530	1368.60, 1732.10 (D.E.) 2243.10 (S.E.) 2754.10
K	^{40}K	Natural decay chain		1.27 × 10^9y		1460.70
Sc	^{46}Sc	^{45}Sc (n · γ) ^{46}Sc	100	83.80 d	26.5	889.30, 1120.50
Fe	^{59}Fe	^{58}Fe (n · γ) ^{59}Fe	0.31	44.6 d	1.15	1099.14, 1291.60
La	^{140}La	^{139}La (n · γ) ^{140} La	99.91	40.27 hr	9.0	328.76 815.78, 1596.17
Ra	^{226}Ra with daughters	Natural decay chain		1600 y		241.98, 295.10, 351.19, 609.30, 1120.30 1238.00, 1377.70, 1728.80, 1764.51 2204.00
Th	^{228}Th	Natural decay chain		1.91 y		238.20, 763.30 1592.47 (D.E.) 2105.47 (S.E.) 2614.47
U	^{239}Np	Decay of U due to ^{238}U (n · γ) ^{239}U	99.28	7.59		209.80, 228.10 277.50

The net peak area of the gamma-ray photo-line at 2754.00 keV as well as the gamma-ray lines at the single and double escape peaks of this line at 2243.00 and 1732.00 keV respectively are plotted against the concentration values of Na as shown in Fig. (7).

The net peak areas of the same gamma-ray lines appeared in the spectrum of phosphate ore sample had been calculated and the concentration percentage values of Na in this ore were obtained as listed in Table (5). The data obtained was corrected for background and it was found that the average corrected value of sodium concentration percentage in phosphate ore sample was at (9.17 ± 0.33%) which was in fair agreement with the value obtained by the first method. Taking into consideration the errors in these results, one can say that they were in a good agreement with the data reported in ref.[24].

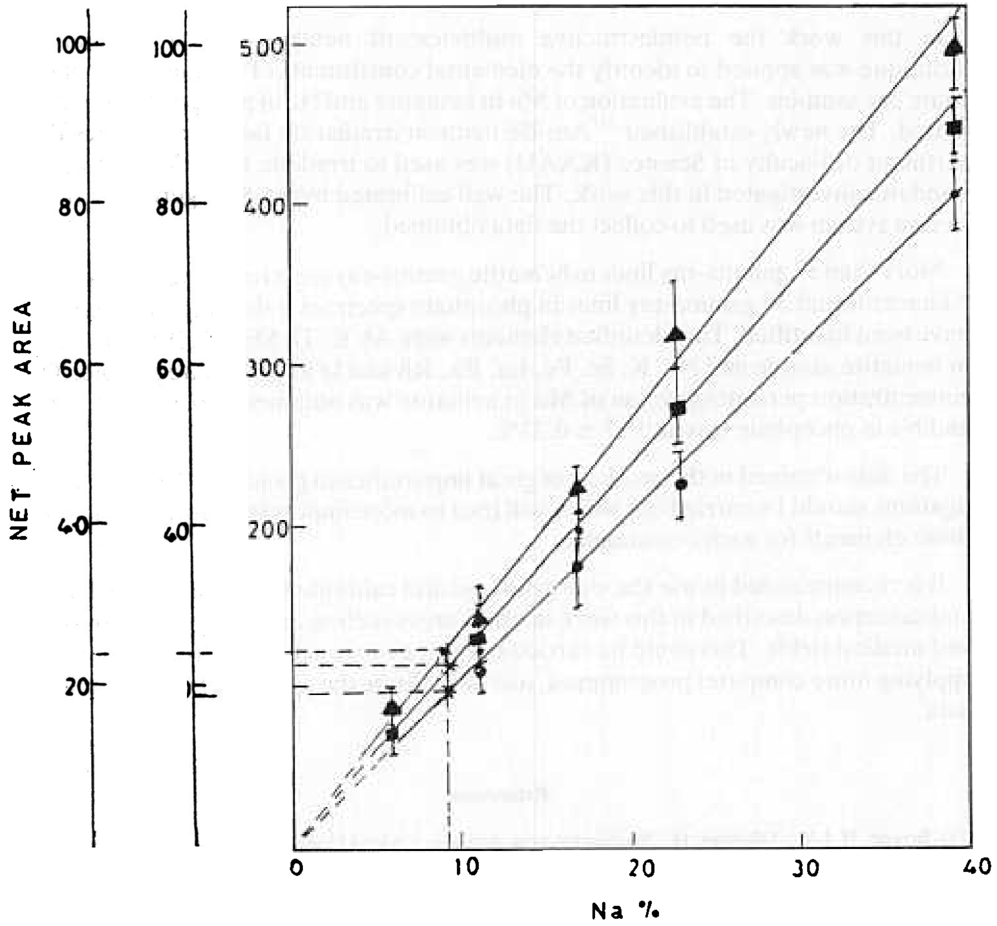


FIG. 7. Calibration curves for Na determination in phosphate ore sample using the photo gamma-ray line at 2754.10 keV (■), the single escape line at 2243.10 keV (●), and the double escape line at 1732.10 keV (▲).

TABLE 5. The percentage concentration value of Na element in phosphate ore sample obtained by using the sensitivity curves of the gamma-ray photo line at 2754.00 keV and the single escape line at 2243.10 keV and the double escape line at 1732.10 keV. (The data is corrected for background).

γ-Ray line in keV	The percentage concentration value obtained for Na	The average value of the present work	Ref. (24) and (25)
2754.00 2243.10 1732.10	9.22 ± 0.30 9.10 ± 0.40 9.20 ± 0.30	9.167 ± 0.333 %	9.490 ± 0.480

Conclusion

In this work the nondestructive multielement neutron activation analysis technique was applied to identify the elemental constituents of hematite and phosphate ore samples. The evaluation of Mn in hematite and Na in phosphate were presented. The newly established ^{241}Am-Be neutron irradiation facility at Physics Department of Faculty of Science (KAAU) was used to irradiate the samples and the standards investigated in this work. The well calibrated hyper pure germanium detection system was used to collect the data obtained.

More than 35 gamma-ray lines in hematite gamma-ray spectrum were belonging to 8 elements and 30 gamma-ray lines in phosphate spectrum belonging to 8 elements have been identified. The identified elements were Al, K, Ti, Mn, Fe, As, Eu and Ra in hematite sample and Na, K, Sc, Fe, La, Ra, Rh and U in phosphate sample. The concentration percentage value of Mn in hematite was obtained as 0.332 ± 0.031% and Na in phosphate was at 9.17 ± 0.33%.

The data obtained in this work, is of great importance to geologists. Further investigations should be carried out which will lead to more important information about these elements for each ore sample.

It is recommended to use the well prepared and calibrated facilities of irradiation and detection described in this work in other areas such as environmental industrial and medical fields. This could be carried out using more active neutron sources and applying more computer programmes, just to facilitate the analysis of such promising data.

References

[1] **Bowen, H.J.M., Gibbons, D.,** *Radioactivation Analysis,* Oxford University Press, London, England (1983).

[2] **Sullivan, W.H.,** *Tri-linear Chart of Nuclides,* V.S. Government Printing Office, Washington, D.C. (1987).

[3] **Eggebert Seelamnn, W., Prening, G., Munzel, Zundei G.,** *Chart of Nuclides,* Second Ed., Second Reprint (1965).

[4] **Gibos, R.C., Way, K.,** *Directory of Nuclear Data Tabulations,* National Academy of Sciences, National Research Council (1958).

[5] **Strominger, D., Hollander, J.M.** and **Seabory, G.T.,** Table of Isotopes, *Rev. Med. Phys.* **30:** No. (2), Pt. II (1958).

[6] **Way, W., Ed.,** *Nuclear Data Cards, National Research Council* (1955).

[7] **Raden, I.M.H., Pearson, G.J., Bewers, J.M.,** Isotope Catalogue for Instrumental Activation Analysis, II. *Radional J. Chem.*, *No. 2: 273-497 (1971).

[8] **Gronthamel, C.E.,** *Applied Gamma-Ray Spectrometry International Series on Analytical Chemistry,* Vol. 2, Pergamon Press (1980).

[9] **Salman, L.,** Radiochemical Method of Analysis, Vol. II. *Proceedings of Symposium, Salzburg, 19, 23, October, 1964. IAEA Vienna,* p. 125 (1965).

[10] **Wainerdi, R.E., Fite, L.E., Steole, E.L.,** *L' Analyze Par Radioactive et ses Applications aus Sciences Biologiques,* Presses Universities de France, Paris, p. 171 (1964).

[11] **Goey, J.J.M.,** (Interkunersitair Reactor Institute Delft (Netherlands) CONF, 710626-1) (1971).

[12] **Kock, R.C.,** *Activation Analysis Hand Book,* Academic Press, New York (1960).

[13] **Lyon, W.S.,** *Guide to Activation Analysis,* D. Van Nostrand Co. Inc., Princeton, N.J. (1984).

[14] **Taylor, D.,** *Neutron Irradiation and Activation Analysis,* George New. Ltd., London (1964).

[15] **Krüger, P.,** *Principles of Activation Analysis,* New York, John Wiley & Sons, Inc., p. 529 (1971).

[16] **Lenihan, J.M.A., Thomson, S.J.,** *Activation Analysis,* Academic Press, London (1965).

[17] **Naslov, L.A.,** *Neutron Activation Analysis,* SSR, p. 192 (1971).

[18] **Maslov, L.A., Luknitskii, V.A.,** *Neutron Activation Analysis Handbook,* I. Datail St., Nauka Leningrad (1971).

[19] **Raoof, M.A., Naeem, A., Zaghloul, R., Abdul-Fattah, A.F.** and **Obied, M.A.,** Multielement Neutron Activation Analysis of an Iron Ore, *Journal of Radioanalytical Chemistry.* **60,** (1): 273-279 (1990).

[20] **Heath, H.L.,** *Gamma-ray Spectrum Catalogue, GE (Li) and Si(Li) Spectrometry,* third edition. Vol. 2, Prepared for the U.S. Atomic Energy Commission Idalio operations office under Contract No. at 919-1) 1375 (1978).

[21] **Lederer, C.M., Shirley, V.S., Browne, E., Dariki, J., Doebler, R., Shihab-Eldin, A., Jardine, L., Tuli, J., Buyrn, A.,** *Table of Isotopes,* 7th edition. Wiely Interscience Publication (1978).

[22] **EG.** and **Ortec, G.,** *Quick List of Nuclear Decay Data,* Published by Academic Press, Including Vol. 36, No. 2, June (1982).

[23] **Tanner, A.B.** and **Senftle, F.E.,** U.S. Geological Survey 990 National Center Reston, Virginia 22092 *U.S. Geological Survey Open File Rep. 78-531,* Table of Photopeak Useful in Nuclear Geophysics, May (1978).

[24] **Hameed-Eldeen, S.A.,** *Uses of Neutron Capture Gamma-Ray Spectroscopy for Multi-element Analysis of Complex Samples,* Ph.D., Thesis, Girls College, Jeddah, S.A. (1989).

[25] **Abdul-Momen, M.A., Hameed-Eldeen, S.** and **Hassan, A.M.,** *Arabian Journal for Science and Engineering,* **15**(2A): 205-212 (1990).

التحليل بالتنشيط الإشعاعي بالنيوترونات لعينتين من خامي الهيماتيت والفوسفات السعودي باستخدام وسيلة ^{241}Am-Be للتشعيع

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المستخلص . تم في هذا البحث عمل التحليل النوعي للعناصر المكونة لخامين من خامات المملكة العربية السعودية، وهما الهيماتيت من منطقة الشميسي والفوسفات من منطقة السنام .

وأمكن تقدير النسبة المئوية لعنصر المنجنيز في الهيماتيت وعنصر الصوديوم في الفوسفات ، وذلك باستخدام تقنية التنشيط الإشعاعي بالنيوترونات .

وقد عُرِّضت العينات المستخدمة في هذا العمل والمعدة إعدادًا خاصًا إلى فيض من النيوترونات الحرارية قدره 1.9×10^{3} n/cm^{2}s ، حيث استخدم لذلك وسيلة التشعيع بالنيوترونات التي تم تصميمها وإعدادها بقسم الفيزياء بكلية العلوم بجامعة الملك عبد العزيز ، والتي استخدم بها مصدر النيوترونات النظائري ^{241}Am-Be 5 Ci .

كما أمكن تجميع الطيف الجامي الناتج عن تشعيع العينات المستخدمة بواسطة مطياف جامي يحوى كاشف للأشعة الجامية من نوع الجرمانيوم بالغ النقاوة ، والذي تم معايرته بالنسبة للطاقات الجامية والكفاءة بدقة عالية .

وبالنسبة لخام الهيماتيت فقد ظهر في الطيف الجامي الآجل نتيجة لتشعيع عينة منه حوالي 35 خطًا جاميًا واضحًا ، تم تحديد طاقة كل خط بمعاونة برنامج محدود للحاسب الآلي الشخصي أعد لهذا الغرض ، واتضح أن هذه الخطوط الجامية كانت للعناصر (Al, K, Ti, Mn, Fe, As, Eu & Ra) ، وقد تم تحديد النسبة المئوية للمنجنيز (Mn) في خام الهيماتيت بالمقدار 0.332 ± 0.031% .

أما بالنسبة لخام الفوسفات فقد ظهر في الطيف الجامي الآجل المقاس نتيجة لتشعيع عينة من هذا الخام حوالي ثلاثون خطًا جاميًا واضحًا للعناصر (Na, K, Sc, La, Ra, Th & U) ، كما تم تحديد النسبة المئوية للصوديوم في خام الفوسفات بالمقدار 9.17 ± 0.33% .