Journal of the Argentine Chemical Society

URANIUM ABUNDANCE IN SOME SUDANESE PHOSPHATE ORES

Abdelmajid A. Adam[1♥] and Mohamed Ahmed H. Eltayeb[2]

[1]Department of Chemistry, Faculty of Science, Taif University, 888 Taif, Saudi Arabia

[2]Sudan Atomic Energy Commission, Khartoum, P.O. Box 3001, Sudan

Received April 5, 2010. In final form July 28, 2010

Abstract

This work was carried out mainly to analysis of some Sudanese phosphate ores, for their uranium abundance and total phosphorus content measured as P_2O_5%. For this purpose, 30 samples of two types of phosphate ore from Eastern Nuba Mountains, in Sudan namely, Kurun and Uro areas were examined. In addition, the relationship between uranium and major, and trace elements were obtained, also, the natural radioactivity of the phosphate samples was measured, in order to characterize and differentiate between the two types of phosphate ores. The uranium abundance in Uro phosphate with 20.3% P2O5 is five time higher than in Kurun phosphate with 26.7% P_2O_5. The average of uranium content was found to be 56.6 and 310 mg/kg for Kurun and Uro phosphate ore, respectively. The main elements in Kurun and Uro phosphate ore are silicon, aluminum, and phosphorus, while the most abundant trace elements in these two ores are titanium, strontium and barium. Pearson correlation coefficient revealed that uranium in Kurun phosphate shows strong positive correlation with P_2O_5, and its distribution is essentially controlled by the variations of P_2O_5 concentration, whereas uranium in Uro phosphate shows strong positive correlation with strontium, and its distribution is controlled by the variations of Sr concentration. Uranium behaves in different ways in Kurun phosphate and in Uro phosphate. Uro phosphate shows higher concentrations of all the estimated radionuclides than Kurun phosphate. According to the obtained results, it can be concluded that Uro phosphate is consider as secondary uranium source, and is more suitable for uranium recovery, because it has high uranium abundance and low P_2O_5%, than Kurun phosphate.

Keywords: phosphate ores; uranium abundance; radionuclides; natural radioactivity

♥Corresponding author. E-mail: majidadam@yahoo.com Tel. : + 9665052099808

Resumen

Este trabajo se llevó a cabo principalmente para analizar algunos minerales de fosfato de Sudán con el objetivo de evaluar la abundancia de uranio y el contenido de fósforo total en los mismos. Para este propósito, se examinaron 30 muestras de dos tipos de mineral de fosfato de las montañas de Nuba oriental en Sudán llamadas Kurun y areas de Uro. Además, se han obtenido las relaciones entre el uranio y los elementos principales y trazas. Se midió también la radiactividad natural de las muestras de fosfato, a fin de caracterizar y diferenciar entre los dos tipos de minerales de fosfato. La abundancia de uranio en fosfatos de Uro con 20,3% P_2O_5 resultó ser cinco veces más alto que en los fosfatos de Kurun con 26,7% P_2O_5. El promedio de contenido de uranio fue de 56,6 y 310 mg/kg para los minerales de fosfato de Kurun y Uros, respectivamente. Los elementos principales en los fosfatos de Kurun y Uros fueron silicio, aluminio y fósforo, mientras que los elementos traza más abundantes en estos dos minerales fueron titanio, estroncio y bario. El coeficiente de correlación de Pearson reveló que el uranio en los fosfatos de Kurun muestra una correlación fuertemente positiva con P_2O_5, y su distribución está controlada esencialmente por las variaciones de la concentración de P_2O_5, mientras que el uranio en los fosfatos de Uro muestra una fuerte correlación positiva con estroncio, y su distribución está controlada por las variaciones de la concentración de Sr. El uranio se comporta de diferentes maneras en los fosfatos de Kurun y de Uro. Los fosfatos de Uro muestran las mayores concentraciones de todos los radionucleidos estimados que los fosfatos de Kurun. De acuerdo con los resultados obtenidos, se puede concluir que los fosfatos de Uro se pueden considerar como fuente secundaria de uranio y que es más adecuado para la recuperación de uranio, debido a su mayor abundancia de uranio y a su menor porcentaje de P_2O_5 que los fosfatos de Kurun.

Palabras clave: minerales de fosfato; abundancia de Uranio; radionucleidos; radioactividad natural

Introduction

Phosphate ore is a complex material; the principal mineral constituent is fluoroapatite, which contains calcium, phosphate, fluoride, carbonate and other elements or groups bound together in the crystal lattice. Phosphate ore is important natural sources of fertilizers, and is used widely in chemical industry. In addition, phosphate ores commonly contain relatively high concentrations of useful elements such as uranium, fluorine, and vanadium, and are commonly associated with organic-rich mudstones, which are potential hydrogen sources rocks [1]. Generally, phosphate ore deposits areas are areas of high radioactivity. The phosphate ore contains natural radionuclides such as U-238, Th-232, Ra-226, and K-40. The decay chain of U-238 and Ra-226 is the main source of radionuclides in phosphate ore [2]. Sedimentary phosphate ores tend to have high concentrations of uranium in the range of 50-200 mg/kg [3], whereas magmatic ores, such as apatite, do not. Typical activity concentrations of ^{238}U are 1500 Bq/Kg in sedimentary phosphate deposits and 70 Bq/Kg in apatite. Uranium-238 is generally found in radioactive equilibrium with its decay products, such as Ra-226. The activity concentrations of ^{232}Th and ^{40}K in sedimentary phosphate rocks are much lower than those of ^{238}U, and comparable to those normally observed in soil [4]. Phosphate ores are economical material used in the manufacturing of phosphoric acid and fertilizers. In view of the harmful effects on human health due to the mining and processing of phosphate ore for the manufacturing of agricultural fertilizers, and other chemical products, it is important to analyze phosphate ores for uranium content and elemental composition, because of the possible migration of elements from the fertilizers to soil and plants, and via the food chain, to human begins where this may results in health effects [5].

In Sudan, because it a big agricultural country, there is a great need to obtain cheap and safe resources of phosphate ores for phosphoric acid and phosphate fertilizer industry. The need to fertilizers increases annually with the increases of Sudan population and the global demand of grains. Brinkman in 1986 [6] discovered two types of phosphate deposits in Kurun and Uro areas in the center of eastern Nuba Mountains. Nevertheless, before the use of these phosphates as fertilizers, was necessary to check them chemically, for major and trace elements, especially for

uranium, and radiologically. Presently, phosphate ore from Kurun and Uro areas are became the subject of intensive studies carried out by several investigators. The natural radionuclide content of phosphate ore have been documented by several works [7,8]. Sam [8] have reported that, phosphate ore generally have high concentration of ^{238}U, he found that ^{238}U and its decay products are the principle contributors of radioactivity in both phosphate deposits, with activity concentrations ranging from 1225-13745 Bq/Kg (Uro phosphate) and 146.5-686.2 Bq/kg (Kurun phosphate). The importance of phosphate ores not came from using it for manufacture of phosphate fertilizer only, but it consider the only uranium resource, which discovered in Sudan by now.

The objectives of the present work are to determine uranium abundance in Kurun and Uro phosphate in order to evaluate its utilization as a uranium source, and to obtain its relationship to major and trace elements. In addition, the activity concentrations of the natural radionuclides have been measured by gamma-ray spectrometry, in order to characterize and differentiate between the two ores.

Area descriptions

The present work is confined to a limited part of the Kurun and Uro areas. These two locations lie in the center of eastern part of the Nuba Mountains in the state of Kordofan, (Sudan) at the intersection at North east of the coordinate 11° 45′ north and 31° 22′ east, between Abu Giubiha and El Rashad towns [9]. Kurun deposits consist of metamorphic graphite schist breccia, and quartzite breccia. The breccia fragments consist of graphite bearing chest components cemented by phosphate. The breccia is presumably of tectonic origin. Apatite igneous as single crystals and some other microcrystalline-phosphate were also observed [6]. Uro deposits consist of volcano sedimentary rocks, omphiolyte assemblage, and quaternary sediments including rocks that belong to green schist facies consisting of a variety of schist, e.g. chlorite phyllite, chlorite schist, mica schist, graphite schist, marbles and quartz [8]. Figure 1 shows the location map of the study areas.

Figure 1. Map of Sudan showing the location of the study area.
■ The study area.

A total of 30 composite surface rock phosphate samples were collected from Kurun and Uro phosphate deposits (15 samples for each area). A chisel and hammer were used to break off the

phosphate chips, which were then collected in cloth bags. Samples were crushed in a jaw crusher and then ground to very fine powder.

Experimental

Dissolution of phosphate ore and AAS analysis

One gram of phosphate ore, previously ground, thoroughly homogenized, and dried, was digested in concentrated nitric acid on a low temperature for 1-2 hours. After evaporating twice to dryness with nitric acid, the residue was treated with 1:1 hydrochloric acid to remove adhering matter. Insoluble material (mainly silica) was removed by filtering off a dense filter paper, and then the filter paper and the filtrate were washed with hydrochloric acid to free from iron. The filter paper was then ignited in a platinum crucible, and the reside was treated with hydrofluoric acid (48%). Finally, the residue was heated with 1:1 sulphuric acid to expel nitric acid, and was added to the filtrate to form the leash liquor solution. A PERKIN-ELMER Atomic absorption spectrometer, with flame atomization using air and acetylene, was used for the determination of Co, Cu, Zn, Pb, Mn, Ti, Mo, Ni, Zr, Sr, Ba, and Cr in the leash liquor solution [10]. The validation of this method was tested by applying the same procedure described above on a certified reference material provide from Institute for Reference Materials and Measurements (IRMM), (sample code: BCR-143R). The results based on the average of triplicate measurements are given in Table 1. The findings are in good agreement with the reference values of some trace element within ± 2% experimental error.

Table 1. Determination of some trace elements in certified reference material (BCR-143R) by AAS method.

Substance	Reference value (mg/kg)	Measured value (mg/kg)	± % Deviation
Cd	71.80	70.45	-1.88
Co	12.30	12.55	+2.03
Cu	130.60	131.32	+0.55
Hg	1.10	1.07	-2.73
Mn	904.00	889.00	-1.66
Ni	299.00	295.00	-1.34
Pb	179.7.00	183.15	+1.92
Zn	1055.00	1070.00	+1.42

XRF analysis

The samples were analyzed for major elements; P_2O_5, SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, and K_2O as well as for uranium using a micro-computer-energy-depressive x-ray fluorescence spectrometer, with Molybdenum secondary target and a molybdenum filter, with Cd-109 excitation source, ($t_{½}$ = 1.34 years, E=22.2 KeV and 88.0 KeV), coupled with a Si(Li) detector and multi-channel analyzer to data counting. The phosphate ore samples were further ground to fine powder of a mean particle diameter of 50 μm. Approximately 500 mg of each samples was moistened with 5-6 drops of binder (10% solution of styropore in toluene), thoroughly homogenized and allowed to dry, and then pressed into pellets of 100 mg/cm^2 ready for analysis.

The concentration of detectable elements were made from the measured net intensity of the corresponding fluorescent x-rays combined with elemental sensitivity factor and coefficient of absorption in the residual matrix of the specimen through iteration procedure [11,12,13]. The method has been successfully applied to the certified reference material (BCR-143R).

Gamma-ray spectrometry analysis

The gamma-activity due to: ^{238}U, ^{235}U, ^{230}Th, ^{232}Th, ^{226}Ra, ^{234}Pa, ^{214}Pb, ^{210}Pb, ^{214}Bi and ^{40}K in phosphate ore samples was measured directly using gamma-ray spectrometry system equipped with high-purity germanium detectors (HPGe) of 35% relative efficiency and 2 KeV relative resolution, connected to ND6600 MCA. The detectors were calibrated for different geometries using Amersham mixed radionuclide standards. The samples were sealed in polyethylene containers with a plastic cover and stored for more than 30 days to attain the equilibrium state between radon and radium. At the end of the ingrowths period, the samples were counted for two days to validate the measurements within the 5% standard deviation at the 95% confidence interval [7,8].

Results and Discussion

Uranium abundance

Table 2 shows that uranium content is very high in all of the collected samples relative to the average uranium content in the earth's crust and shale rocks which is 2.7 and 3 mg/kg, respectively [14,15]. On the other hand, the Uro phosphate samples show very high contents relative to the average of the word phosphates (120 mg/kg) [16].

Table 2. Uranium content and P_2O_5% for phosphate ore samples from Kurun and Uro areas.

Phosphate ore type					
Kurun phosphate			**Uro phosphate**		
Sample No.	**Uranium content (mg/kg)**	**P_2O_5%**	**Sample No.**	**Uranium content (mg/kg)**	**P_2O_5%**
1KPO	53.000	25.411	1UPO	100.500	22.633
2KPO	70.300	35.233	2UPO	129.200	16.700
3KPO	27.700	23.500	3UPO	94.300	18.000
4KPO	65.600	33.400	4UPO	1050.000	16.900
5KPO	86.200	20.122	5UPO	245.000	20.341
6KPO	38.500	21.000	6UPO	137.100	17.500
7KPO	33.000	29.500	7UPO	175.100	25.036
8KPO	109.600	40.473	8UPO	556.200	20.800
9KPO	41.400	25.200	9UPO	219.000	24.263
10KPO	21.700	20.000	10UPO	164.700	19.300
11KPO	19.200	18.300	11UPO	800.600	23.622
12KPO	95.100	24.451	12UPO	322.000	21.542
13KPO	61.000	29.500	13UPO	204.400	23.400
14KPO	50.100	26.300	14UPO	113.000	17.966
15KPO	77.000	28.112	15UPO	338.900	16.500

KPO: Kurun phosphate ore samle

UPO: Uro phosphate ore sample

The statistical analysis of the results given in Table 3 shows the followings:

- The estimated phosphorus pentoxide ratio (P_2O_5%) in Kurun and Uro areas range from 16.5-40.47%. The mean total phosphorus in Kurun and Uro phosphate ores are 26.70 and 20.30%, respectively. Generally, the phosphate ore of Kurun and Uro areas can be considered as a typical phosphate ore.
- There is a significant difference in the uranium abundance between Kurun and Uro areas. Uro phosphate has uranium content five times higher than Kurun phosphate, but has low P_2O_5 percentage, whereas Kurun phosphate has P_2O_5 higher than Uro phosphate, but low uranium content. In Kurun phosphate, the uranium contents range between 19.2 - 109.6 mg/kg, and 94.3 – 1050 mg/kg in Uro phosphate.
- A positive relation exists between uranium content and P_2O_5% in phosphate ore samples from Kurun area (r = +0.58), which contain 56.63 mg/kg uranium in average.
- There are no relation between uranium content and P_2O_5% in phosphate samples from Uro area (r = -0.04), which contain higher uranium concentration than Kurun area with an average of 310 mg/kg.

The chemical analysis of phosphate ore samples indicates that in case of phosphate samples that contain low uranium concentration, there is a strong positive correlation between uranium content and P_2O_5%, but if uranium concentration increases over 60 mg/kg, no correlation is exited.

Table 3. Summary of the statistics of the uranium content and P_2O_5% results.

Statistic data	**Phosphate ore type**			
	Kurun phosphate		**Uro phosphate**	
	Uranium content (mg/kg)	P_2O_5%	Uranium content (mg/kg)	P_2O_5%
Range	19.20 - 109.60	18.30 - 40.47	94.30 – 1050.00	16.50 - 25.04
Mean value	56.63	26.70	310.00	20.30
Standard deviation	26.45	6.19	202.36	2.56
Correlation coefficient	0.58		-0.04	

Uranium behavior

The major elemental percentage and the concentrations of trace elements of phosphate ores in Kurun and Uro samples are summarized in Tables 4 and 5. The data in these tables show that the major elements in phosphate ore samples from Kurun and Uro areas are Silicon, phosphorus, and aluminum. Kurun and Uro phosphate ores have shown several geochemical similarities. Elemental percentage of SiO_2, CaO, MgO, and Na_2O in Kurun and Uro phosphate have a certain similarity, while in P_2O_5, Al_2O_3, Fe_2O_3 and K_2O, this similarity is very low. The most abundant trace elements in these two areas are Ti, Sr and Ba. Zinc, Mo, Pb, Ni, and Ba concentrations are relatively higher in Kurun phosphate ore, whereas, cobalt and Ti are higher in Uro phosphate ore. Concentrations of strontium, Mn, Cu, Cr and Zr in Kurun and Uro phosphate have a certain similarity, while in Co, Zn, Pb, Ti, Mo, Ni and Ba, this similarity is very low.

Uranium content increases significantly in Uro phosphate as P_2O_5% descends to 20% with an average of 310 mg/kg uranium. Its content drops with P_2O_5% exceeds than 25% with an average

of 56.63 mg/kg in Kurun phosphate. The behavior of uranium in Kurun and Uro phosphate indicates that when P_2O_5% is less than 21% the phosphate shows marked enrichment in uranium by a factor of about 5.5 than phosphate with P_2O_5% more than 21%. Tables 6 and 7 show the pearson correlation coefficient between major and trace elements, and uranium in Kurun phosphate ore samples, whereas Tables 8 and 9 show the Pearson correlation coefficient for Uro phosphate ore samples.

Table 4. Major elemental percentage in Kurun and Uro phosphate ore samples.

Major element	Mean percentage (%)	
	Kurun phosphate (n=15)	Uro phosphate (n=15)
P_2O_5%	26.700	20.300
SiO_2%	40.000	42.000
Al_2O_3%	15.800	21.100
Fe_2O_3%	4.100	1.600
CaO%	5.000	4.700
MgO%	0.140	0.210
Na_2O%	0.112	0.330
K_2O%	0.800	0.050

Table 5. Trace element concentrations in Kurun and Uro phosphate ore samples in (mg/kg).

Trace element	Mean concentration (mg/kg)	
	Kurun phosphate (n=15)	Uro phosphate (n=15)
Co	71.00	128.51
Cu	432.11	309.01
Zn	1050.02	475.70
Pb	201.00	116.60
Mn	555.03	358.52
Ti	4880.00	7300.01
Mo	381.03	221.66
Ni	311.00	151.01
Zr	175.90	115.30
Sr	2778.02	2630.06
Ba	1400.06	931.00
Cr	144.00	104.55

The Pearson correlation coefficients show that uranium in Kurun phosphate has strong positive correlation coefficient with P_2O_5 and Mn, and moderate positive correlation with MgO,

CaO, Pb and Ti. This may indicate the close relationship between uranium and these elements in Kurun phosphate minerals. Uranium in Uro phosphate has strong positive correlation with Sr, and moderate positive correlation with Zr. The variation of uranium content in Kurun phosphate appears to be generally controlled by the variations of P_2O_5 and Mn , and is not related to the abundance of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, Co, Cu, Zn, Pb, Ti, Mo, Ni, Zr, Sr, Ba and Cr. In Uro phosphate, the variation of uranium content appears to be generally controlled by only Sr, and is not related to any major element. Figure 2 shows the variation diagrams of strong and moderate positive correlation elements against uranium in Kurun and Uro phosphate.

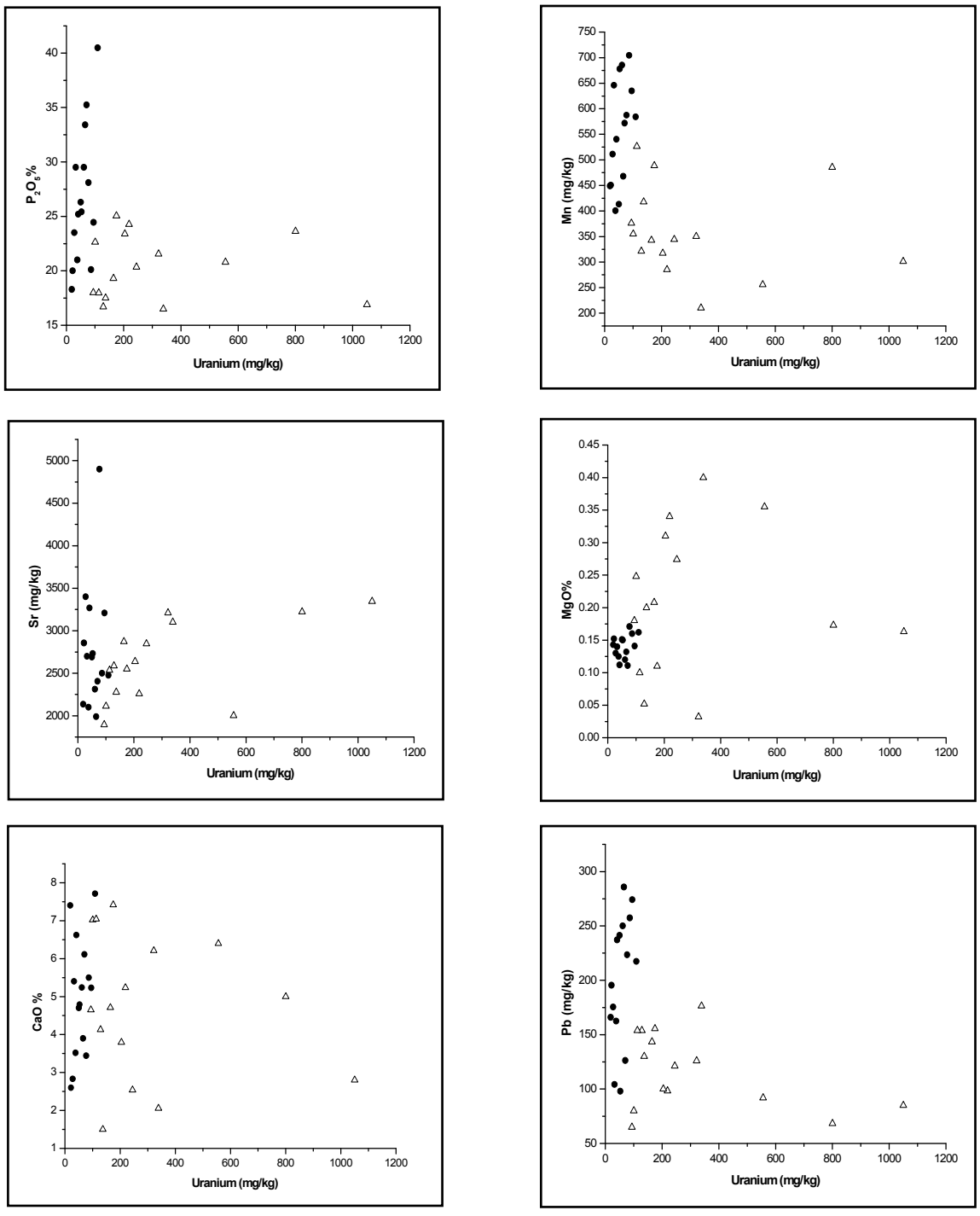

Figure 2.

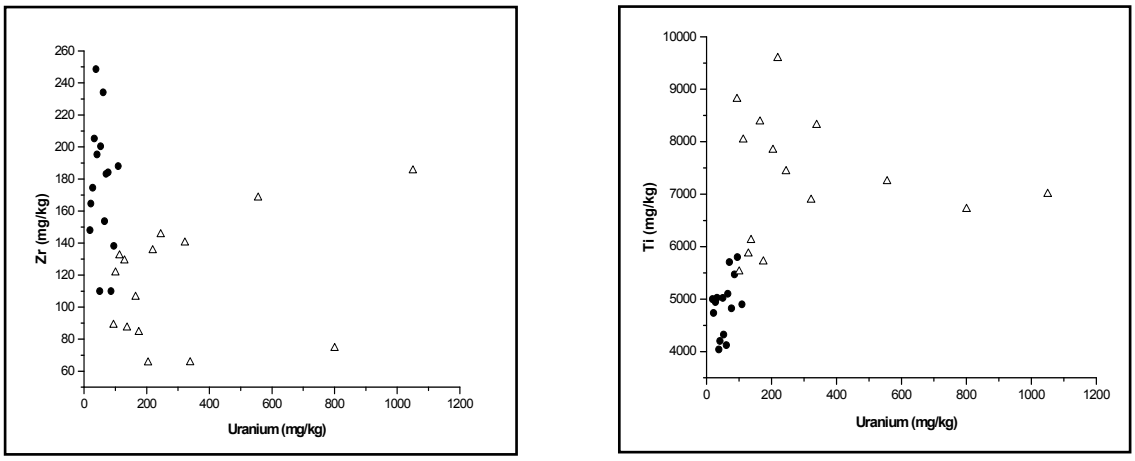

Figure 2. Variation diagrams of strong and moderate positive correlation element against uranium content in Kurun and Uro phosphate. • Kurun phosphate. Δ Uro phosphate.

Table 6. Pearson correlation coefficient between the major elements and uranium in Kurun phosphate ore samples.

	P_2O_5%	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	Na_2O%	K_2O%	U(mg/kg)
P_2O_5%	1.00								
SiO_2%	-0.13	1.00							
Al_2O_3%	-0.34	-0.23	1.00						
Fe_2O_3%	-0.27	-0.28	0.04	1.00					
CaO%	0.33	-0.60	0.16	-0.08	1.00				
MgO%	-0.07	-0.32	-0.52	0.44	-0.09	1.00			
Na_2O%	-0.21	-0.60	0.37	0.04	0.36	0.02	1.00		
K_2O%	-0.29	0.06	0.34	-0.39	0.19	-0.50	0.18	1.00	
U (mg/kg)	0.58	-0.15	-0.44	-0.38	0.33	0.32	-0.18	0.02	1.00

Table 7. Pearson correlation coefficient between the trace elements and uranium in Kurun phosphate ore samples.

	U	Co	Cu	Zn	Pb	Mn	Ti	Mo	Ni	Zr	Sr	Ba	Cr
U	1.00												
Co	-0.11	1.00											
Cu	-0.50	-0.44	1.00										
Zn	-0.11	-0.34	0.15	1.00									
Pb	0.46	0.34	-0.59	0.12	1.00								
Mn	0.51	-0.37	-0.15	-0.38	-0.04	1.00							
Ti	0.41	-0.15	0.12	-0.06	0.16	0.16	1.00						
Mo	-0.10	0.64	-0.21	-0.14	-0.03	-0.29	0.16	1.00					
Ni	0.21	-0.13	0.09	0.08	0.12	-0.18	0.16	-0.20	1.00				
Zr	-0.19	0.01	0.002	-0.16	-0.44	0.09	-0.70	-0.27	-0.25	1.00			
Sr	0.12	-0.36	0.31	0.01	0.09	0.18	0.03	-0.50	0.42	-0.04	1.00		
Ba	-0.08	0.27	-0.03	-0.27	0.03	0.23	-0.61	-0.14	0.12	0.37	0.12	1.00	
Cr	-0.03	0.23	0.12	0.19	0.22	-0.12	0.29	0.10	0.05	-0.08	-0.05	-0.16	1.00

Table 8. Pearson correlation coefficient between the major elements and uranium in Uro phosphate ore samples.

	P_2O_5%	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	Na_2O%	K_2O%	U(mg/kg)
P_2O_5%	1.00								
SiO_2%	-0.32	1.00							
Al_2O_3%	-0.52	0.34	1.00						
Fe_2O_3%	0.09	0.35	-0.10	1.00					
CaO%	0.55	0.18	-0.35	0.08	1.00				
MgO%	0.12	-0.23	0.002	0.25	-0.31	1.00			
Na_2O%	-0.18	-0.40	0.10	-0.34	-0.29	-0.17	1.00		
K_2O%	-0.19	0.16	-0.18	0.37	0.16	0.13	0.18	1.00	
U(mg/kg)	-0.04	0.20	0.29	-0.36	-0.18	0.06	-0.22	-0.67	1.00

Table 9. Pearson correlation coefficient between the trace elements and uranium in Uro phosphate ore sample.

	U	Co	Cu	Zn	Pb	Mn	Ti	Mo	Ni	Zr	Sr	Ba	Cr
U	1.00												
Co	-0.14	1.00											
Cu	-0.09	-0.24	1.00										
Zn	0.04	0.12	0.36	1.00									
Pb	-0.40	0.10	0.23	-0.04	1.00								
Mn	-0.15	0.45	0.14	0.13	0.02	1.00							
Ti	-0.07	0.12	0.04	-0.53	-0.07	-0.32	1.00						
Mo	-0.19	0.32	0.35	-0.25	0.43	0.01	0.56	1.00					
Ni	0.137	-0.10	0.37	-0.32	0.27	-0.20	0.37	0.55	1.00				
Zr	0.37	0.01	0.12	-0.07	-0.18	-0.24	-0.04	0.02	0.28	1.00			
Sr	0.57	0.01	0.34	0.29	0.24	-0.02	-0.06	0.19	0.43	0.03	1.00		
Ba	-0.22	0.76	0.02	0.07	0.47	0.16	0.39	0.65	0.25	-0.14	0.30	1.00	
Cr	-0.14	0.03	0.23	-0.31	-0.05	0.12	0.22	0.15	0.28	0.45	-0.42	-0.18	1.00

Natural radioactivity

The activity concentrations of natural radionuclides from ^{238}U and ^{232}Th decay series, and of ^{40}K, as measured by gamma spectrometer in Kurun and Uro phosphate ore are listed in Table 10.

The data in Table 10 show that phosphate samples from Uro area contain higher concentrations of all the estimated radionuclides than Kurun area. The average activity concentration of ^{238}U, ^{226}Ra and ^{230}Th in Kurun phosphate ore are 621, 644, 553 Bq/Kg, respectively. The corresponding values for Uro phosphate are 3690, 3949, 3222 Bq/Kg, respectively. Concentration of ^{238}U, ^{226}Ra and ^{230}Th in Uro phosphate ore are six times higher than that of Kurun phosphate ore. Thorium-232 shows low concentrations in all measured samples.

The equivalent mass concentrations of uranium in Kurun and Uro phosphate ores are found to be 50.5 and 300 mg/kg, respectively. The equivalent uranium content is generally less than the value measured by x-ray fluorescence, which may indicate a state of non-equilibrium between uranium and its daughters. Uranium exploration has shown the concentrations of uranium in ore of minable grade usually range from 1000-5000 mg/kg, and that concentrations grater than 100 mg/kg

are of potential interest depending on the size of the deposit, and the presence of the recoverable minerals [17]. The data indicate that generally, Uro phosphate ore is more suitable for uranium recovery than Kurun phosphate, because it contain higher uranium concentration, and lower P_2O_5%. The high quantity of P_2O_5 will interfere with uranium in the extraction step, and contaminate the uranium concentrate product. Kurun phosphate ore is more suitable for phosphate fertilizer industry, because it contains higher P_2O_5%, lower uranium content, and lower activity concentrations.

Table 10. Radionuclide activity concentrations in Kurun and Uro phosphate ore.

Radionuclide	Mean Activity (Bq/Kg)	
	Kurun phosphate	**Uro phosphate**
^{238}U	621.00	3690.0
^{235}U	27.30	168.74
^{230}Th	553.00	3222.00
^{232}Th	6.100	6.900
^{226}Ra	644.00	3949.00
^{234}Pa	1030.00	2570.00
^{214}Pb	786.00	1860.00
^{210}Pb	490.50	2709.00
^{214}Bi	1160.00	2370.00
^{40}K	207.30	103.13
eU (ppm)	50.50	300.00

eU = equivalent mass concentration of uranium (1μg = 12.3 mBq)

Conclusions

On the basis of the obtained results of the foregoing study, the following conclusions can be derived:

i) Kurun and Uro areas are areas of trace level of uranium content in the range from 27.7 to 310 mg/kg. Uro phosphate ore shows high significant differences in uranium concentrations than Kurun phosphate. The mean uranium content in Kurun and Uro phosphate ore are 56.6 and 310 mg/kg, respectively.

ii) The uranium contents increases as P_2O_5 less than 21% with an average of 310 mg/kg in Uro phosphate. This value drop to an average of 56.6 mg/kg with P_2O_5 exceeds than 21%.

iii) The main elements in Kurun and Uro phosphate ore are silicon, aluminum, and phosphorus, whereas the most abundant trace elements are iron, titanium, and strontium.

iv) Uranium distribution is controlled by the variation of P_2O_5 in Kurun phosphate. In Uro phosphate, it is controlled by the variation of Sr and is not affected by the variation of any major oxide.

v) Uro phosphate ore type contains higher concentrations of all the estimated radionuclides than Kurun phosphate ore.

vi) The results have evidenced that Uro phosphate is consider as secondary uranium source, and is more suitable for uranium recovery. The phosphate ore of Kurun is more suitable for phosphate fertilizer industry.

Acknowledgements. The authors are extremely grateful to the staff of the Sudan Atomic Energy Commission for their kind assistance in samples analysis. Sincere thanks are also extending to the chemistry department, University of Khartoum, for providing laboratory facilities.

References

[1] P. Becker, *Phosphates and phosphoric acid, fertilizer science and technology*, Marcel Decker Inc., New York, 1993.

[2] C. Jingjian, Z. Yongyi and Y. Juncheng, *Institute for Application of Atomic Ener*gy, CAAS, Beijing, **1992**, 561.

[3] Abd El-Gabar, M. El-Arabi and I. H. Khalifa, *Journal of Environmental Radioactivity,* **2002**, *61*, 169.

[4] A. G. E. Abbady, M. A. M. Uosif and A. El-Taher, *Journal of Environmental Radioactivity*, **2005**, *84*, 65.

[5] P. Hayumbu, N. Haselberger, A. Markowicz and V. Valkovic, *Applied Radiation and Isotopes*, **1995**, *46*, 1003.

[6] K. Brinkman, *The geology and mineralization of basement complex in the northeast Nuba Mountains, Sudan*, Hanover (unpublished report), 1986.

[7] A. K. Sam, and E. Holm, *Science of the Total Environment*, **1995**, *162*, 173.

[8] A. K. Sam, M. M. O. Ahmed, F. A. El Khangi, , Y. O. El Nigumi and E. Holm, *Journal of Environmental Radioactivity*, **1999**, *42*, 65.

[9] A., J. Whiteman, *The geology of the Sudan republic*, Clarendon press, Oxford, Britain, 1971.

[10] L. John, and C. Van, *Analytical atomic absorption spectroscopy*, Academic Press Inc., Toronto, 1980.

[11] R. Jenkens, R. W. Gould, and D. Gedcke, *Quantitative x-ray spectrometry*, Marcel Decker Inc., New York, 1981.

[12] P. O. Ogunleye, M. C. Mayaki and I. Y. Amapu, *Journal of Environmental Radioactivity*. **2002**, 62.

[13] A. R. Hassan, *Prospecting methods for uranium and other associated mineralization in the Nuba Mountains, Sudan*, M.Sc. thesis, University of Khartoum, Sudan, 1989.

[14] K. K. Turekian and K. H. Wedepohl, Geological *Society of America Bulletin*. **1961**, *72*, 175

[15] J. A. S. Adams, Y. K. Osmond, and J. J. W. Rogers, *Physics and Chemistry of the Earth*. **1959**, *3*, 298.

[16] Z. S. Altschuler, *The geochemistry of trace elements in marine phosphorites, Part I: Characteristic abundances and enrichment*, SEPM Special Publication 575-B, 1980.

[17] IAEA, Technical Reports Series No. 186, International Atomic Energy Agency, Vienna, Austria, 1979.

[18] IAEA, Technical Reports Series No. 313, International Atomic Energy Agency, Vienna, Austria, 1990.

[19] IAEA, Technical Reports Series No. 341, International Atomic Energy Agency, Vienna, Austria, 1991.

[20] M. J. C. S. Braganca, L. Tauhata, A. F. Clain and I. Moreira, *Applied Radiation Isotopes*, **2004**, *61*, 351.