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APPLICATION OF THE CD-LINED IRRADIATION CHANNEL OF NIRR-1 AND IMPLEMENTATION OF THE K_0-IAEA PROGRAM TO EVALUATE ELEMENTAL CONTENTS IN CLAY SAMPLES

RAYMOND L. NJINGA[1*], SUNDAY A. JONAH[2] AND MICHAEL O. ADELEYE[3]
[1]Department of Physics, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria.
[2]Center for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.
[3]Department of Physics, Bingham University, New Karu, Nasarawa State, Nigeria.

AUTHORS' CONTRIBUTIONS
This work was carried out in collaboration between all authors. Authors RLN and SAJ designed the study, wrote the protocol and interpreted the data. Authors RLN and MOA anchored the field study, gathered the initial data and performed preliminary data analysis. All the authors managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

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ABSTRACT

The application of the Cd-lined irradiation channel of the Nigeria Research Reactor-1 (NIRR-1) and implementation of k_0-standardization method has been performed on some clay potteries from Tatiko locality, in Niger State-Nigeria. In terms of quality control and assurance of results by the used of the k_0-IAEA installed software, the analysis of the IAEA-SL-1 Lake sediment and the NIST-Coal Fly Ash 1633b were validated. The samples and the Standard Reference Materials (SRMs) were irradiated together with the neutron flux setting of 5.0×10^{11} n cm^{-2} s^{-1} for six hours. After waiting periods of one to five days, the gamma-rays (energies) from the activated samples were measured using the vertical dip-stick ORTEC-GEM-30195 HPGe coaxial detector, with resolution (FWHM) at 1.33 MeV, ^{60}Co to be 1.85 keV and at 122 keV, ^{57}Co to be 0.85 keV. The results obtained using the software agreed well with the certified values of the SRMs. Also, twenty six elements; Al, Mg, Ti, V, Na, K, Dy, Mn, Sc, Co, Rb, Cs, Ba, Eu, Lu, Hf, Ta, Th/Pa, Cr, Fe, As, Br, La, U/Np, Sm and Yb were determined quantitatively using the k_0-IAEA installed software. Among these elements, the concentration in ppm of six rare earth elements (REE) were identified; Dy, Eu, Lu, Yb La and Sm. The overall uncertainties found in the overall analysis of the above mentioned elemental concentrations were generally very low within a statistical value of less than ±2 standard deviation.

Keywords: k_0-IAEA program; flux distribution; cadmium lined; MNSR; NIRR-1; REEs.

1. INTRODUCTION

The k_0- IAEA: International Atomic Energy Agency based Epithermal Cadmium Neutron Activation Analysis (k_0-based EpiCd NAA) is a physical technique applied for the absolute measurement of elemental concentration present in almost all sort of samples. The sample specification ranges from geological to biological, soil, liquid etc. Among the geological samples we have archaeological samples in

**Corresponding author: Email: njingaraymond@yahoo.co.uk;*

which determination of the terrestrial elemental concentration of K, Th and U/Np present led to dating and archaeometry studies [1,2].

This k_0-ENAA method of cadmium lined in the irradiation channel of NIRR-1 actually shields off almost completely [3,4] the thermal neutron irradiation and allow both epithermal and fast neutrons irradiation within the channel to activate different isotopes present in any given matrix [5-7]. The radio nuclides produced in (n,γ) reaction emit gamma-rays that are characteristic of the elements present in sample matrices [8,9].

Miniature nuclear research reactors are the most efficient neutron sources for high sensitivity activation analysis. Recently, a permanent Cd-liner of 0.1mm thick was installed in the larger outer irradiation channel (A-3) of NIRR-1 [9,10]. The validation of the neutron flux levels distribution and stability in five channels using pure copper wires and Al-Au (0.1%) monitor in lined with the nuclear reactions; ^{63}Cu (n, γ)^{64}Cu, ^{197}Au (n, γ)^{198}Au and ^{27}Al (n, p)^{27}Mg, was performed by Njinga et al. [11].

The k_0-IAEA program contain algorithm designed to take care of coincidence summing effects, of photo peaks such as; single escape and double escape peaks, summing between gamma-rays, or involving X-rays following electron capture or internal conversion [11,12]. The k_0-IAEA program is designed and developed for gamma spectral data evaluation and analysis. In this work, we focused on; (1) to install the k_0-IAEA program in our laboratory (2) to implement the newly installed Cd-lined channel for irradiation of samples for analyses, (3) to validate the quality control and assurance of the obtained results using standard reference materials and (4) to evaluate trace, REEs, heavy and light metals in clay samples.

2. THEORY OF TECHNIQUES

To estimate the gamma-ray energy represented by a peak, the position of the peak centroid within a fraction of a channel is calculated as [13]:

$$\text{centriod} = \frac{\sum C_i x}{\sum C_i} \quad (1)$$

Where C_i is the counts in the xth channel

The background region estimated using the channel contents at the upper and lower edges of the peak region follows the basic equations [13];

For the net peak area, this is performed using the equation given as;

$$A = G - B = \sum_{i=L}^{U} C_i - n\frac{(C_{L-1} + C_{U+1})}{2} \quad (2)$$

And the standard deviation of the peak area is calculated as;

$$\sigma_A = \left[A + B\left(1 + \frac{n}{2m}\right)\right]^{1/2} \quad (3)$$

Where n is the number of channels within the peak region and m the number of channels within upper and lower background regions. All measured activities are corrected for radioactive decay to a point in time expressed empirically as [13];

$$R_0 = R_t \exp\left(\frac{\ln 2}{T_{1/2}} \times t\right) \quad (4)$$

Where R_t and R_0 are the disintegration rates at time t and at the reference time and $T_{1/2}$ is the half-life of the nuclide.

In low activity measurement by gamma-ray spectrometer an empirical expression for limit of detection (LOD) measurement in Bq/g of sample matrices is given as [13];

$$LOD\,(Bq/kg) = 2.71 \times 3.29 \times \frac{\left[\left(A_b \times LT_s\right) + 2B_s\right]^{1/2}}{LT_s \times M_s \times P_\gamma \times \varepsilon} \quad (5)$$

Where A_b = net peak area of background measurement (cps), LT_s = live time of sample measurement (s), B_s = peak base of measured sample (counts), M_s = mass of sample (kg), P_γ = probability of emission, ε = full-energy peak efficiency.

However, the mathematical expression for evaluation of concentration of elements (ppm) activated in Cd-lined channel (A-3) is given as [14];

$$concentrat\ \ ion\ (ppm) = \frac{\left(\frac{N_p / t_m}{SCCw}\right)_a}{\left(\frac{N_p / t_m}{SCCw}\right)_m} \cdot \frac{k_{0.Au}(m)}{k_{0.Au}(a)} \cdot \frac{F_{Cd.m} + G_{e.m}\, Q_{0.m}(\alpha)}{F_{Cd.a} + G_{e.a}\, Q_{0.a}(\alpha)} \cdot \frac{\varepsilon_{p.m}}{\varepsilon_{p.a}} \quad (6)$$

Where Np = net peak area, t_m= measurement time, S = saturated time, D = decay factor, C = cooling factor, w= weight of sample, $\varepsilon_{p.m}$ = efficiency of detector at a given distance, F_{Cd} = cadmium transmission factor for both monitor and analyte, G_e = epithermal self-shielding factor for both monitor and analyte.

2.1 Sample Collection

Six samples were collected from 6 sites in Tatiko locality, North central part of Nigeria located in Paikoro local government of coordinates 9°26′N 6°38′E/9.433°N 6.633°E and is covered all over with clay minerals that were formed over long periods of time by the gradual chemical weathering of rocks, usually silicate-bearing. A summary of the sample sites are given in Table 1.

In addition, four samples were collected during and after the production process of clay pots as summarized in Table 2.

3. EXPERIMENTS

The ten samples were manually grinded, in a porcelain mortar using a pestle, followed by sieving aiming at homogenization in a turbulent mixer. They were dried using infrared lamp for 24 hours at 110°C and were packed along with IAEA SL-1 lake sediments and NIST coal fly ash 1633b in an ultraclean irradiation vials (polyethylene capsule) before transferring for irradiation in the cadmium lined channel. The twelve samples were further divided into two groups of six samples each, packaged in a single vial of ~4.5 cm of height and diameter of ~2 cm. The samples were irradiated at a thermal power level of 15.5 kW as shown in Tables 3 and 4 which correspond to a neutron flux value of 5.0 x 10^{11} n cm^{-2} s^{-1} on the control console for 6 hours.

After irradiation, the induced activities in the samples were measured using the vertical dip-stick ORTEC-GEM-30195 HPGe coaxial detector, with resolution (FWHM) at 1.33 MeV, ^{60}Co to be 1.85 keV and at 122 keV, ^{57}Co to be 0.85 keV, peak-to-Compton ratio, ^{60}Co to be 60:1 and relative efficiency of 30% at 1332.5 keV of ^{60}Co at a geometry of 25 cm. With the aid of the Maestro Multi-Channel Analyzer (MCA) emulation software card, coupled to the detector through the ORTEC electronic modules, the nuclear spectrum for the samples were acquired for k_0-IAEA program analysis.

The measurements of the two groups of activated samples were performed in two geometries each, after a waiting period of some few hours as shown in Tables 5 to 8. The first measurements of both the first and second groups were performed at 2 cm for medium and long lived nuclides within some few hours after irradiation to three days for 1800 seconds (Tables 5 and 6). The second measurements of both groups were measured at 2 cm within some few hours after irradiation to five days for long half lived nuclides for 3600 seconds (Tables 7 and 8). The dead time of each measurement did not exceed 6% and the peak statistics was above 0.5% [8].

4. RESULTS AND DISCUSSION

The samples were interpreted based on the gamma energies and half-life of the radionuclides shown in Table 9. The results for the NIST Coal Fly Ash 1633b and IAEA Lake sediments-SL-1 obtained in this work using k_0-ENAA program are listed in Table 10.

Table 1. Sample sites ID and descriptions within ~45 cm to ~800 cm depth

Sites	Sample ID	Description of sample sites
C	45 Tat.1st	Vertical depth of ~45 cm and horizontal length of ~100 cm
H	100 Tat.2nd	Vertical depth of ~100 cm and horizontal length of ~100 cm
F	200 Tat.3rd	Vertical depth of ~200 cm and horizontal length of ~100 cm
G	400 Tat.4th	Vertical depth of ~400 cm and horizontal depth of ~100 cm
B	600 Tat.5th	Vertical depth of ~600 cm and horizontal length of ~100 cm
A	800 Tat.6th	Vertical depth of ~800 cm and horizontal length of ~100 cm

Table 2. Sample ID and descriptions of the archaeological samples

Sites	Sample ID	Description of sample sites
D	1st Tat. MRB	Mixture of deep orange-red clay and brown clay with water ready for firing
E	2st Tat. AHM 3	After firing the molted clay pot
J	3rd Tat. 2 YS	Finished clay pot of approximately two years
I	4th Tat. 1 HYS	Clay pot of about one hundred (100) years old use for cooking

Table 3. Irradiation schedules for 1st group of six archaeological samples in A-3

Sample ID	Sample type	Weight (g)	T_{irr} (hrs)	T_{in} (am)	T_{end} (pm)
013G02	Coal fly ash (1633b)	0.583	6.000	10:41	16:41
013G04	800 Tat. 5th	0.645	6.000	10:41	16:41
013G06	600 Tat. 6th	0.613	6.000	10:41	16:41
013G08	200 Tat. 3rd	0.606	6.000	10:41	16:41
013G10	4th Tat. 1 HYS	0.614	6.000	10:41	16:41
013G12	100 Tat. 2nd	0.623	6.000	10:41	16:41

Table 4. Irradiation schedules for the 2nd group of six archaeological samples in A-3

Sample ID	Sample type	Weight (g)	Tirr (hrs)	Tin (am)	Tend (pm)
013G14	3rd Tat. 2 YS	0.538	6.000	10:09	16:09
013G16	1st Tat. MRB	0.536	6.000	10:09	16:09
013G18	2nd Tat. AHM 3	0.626	6.000	10:09	16:09
013G20	45 Tat.1st	0.646	6.000	10:09	16:09
013G22	400 Tat. 4th	0.506	6.000	10:09	16:09
013G24	IAEA lake sediment	0.547	6.000	10:09	16:09

Table 5. Counting schedules for first group six archaeological samples within one to three days

Sample ID	Sample type	First geom.	Second geom.	Counting time (sec.)
013G02	Coal fly ash (1633b)	15.00	2.00	1800.00
013G04	800 Tat. 5th	15.00	2.00	1800.00
013G06	600 Tat. 6th	15.00	2.00	1800.00
013G08	200 Tat. 3rd	15.00	2.00	1800.00
013G10	4th Tat. 1 HYS	15.00	2.00	1800.00
013G12	100 Tat. 2 nd	15.00	2.00	1800.00

Table 6. Counting schedules for 2nd group of six archaeological samples within one to three

Sample ID	Sample type	First Geom.	Second Geom.	Counting time (s)
013G14	3rd Tat. 2 YS	15.00	2.00	1800.00
013G16	1st Tat. MRB	15.00	2.00	1800.00
013G18	2nd Tat. AHM 3	15.00	2.00	1800.00
013G20	45 Tat. 1st	15.00	2.00	1800.00
013G22	400 Tat. 4th	15.00	2.00	1800.00
013G24	IAEA lake sediment	15.00	2.00	1800.00

The results of the IAEA Lake sediment-SL-1 and NIST Coal Fly Ash 1633b reference standard samples analyzed using the k_0-IAEA software compared well with the certified values as shown in Table 10. On this basis, the following data were obtained for the ten archaeological sediments samples (clay potteries) using the software within some few hours after irradiation to five days as shown in Tables 11 and 12.

From Table 11, K was determined to be 3.31% and 3.03% in A (800 Tat. 5th) and B (600 Tat. 6th) respectively. This element was found to be low in I (4th Tat. 1 HYS) and J (3rd Tat. 2 YS). It was observed that (Table 12) Na, Mg, Ti were all obtained at percentage level implying that they were much in the clay samples. Na was obtained within the range of 0.04% [±0.012] for sample G (400 Tat.4th) and 1.73%

[±0.017] for A (800 Tat. 5th). Mg was found in the range of 0.013% [±0.013] for the clay pot sample (J) that was two years old and 1.17% [±0.015] for sample D which was the molded clay pot sample ready to be heated.

Table 7. Counting schedules for six archaeological samples within five days

Sample ID	Sample type	Counting time (s)	Geom. (cm)
013G02	Coal fly ash	3600.00	2.00
013G04	800 Tat. 5th	3600.00	2.00
013G06	600 Tat. 6th	3600.00	2.00
013G08	200 Tat. 3rd	3600.00	2.00
013G10	4th Tat. 1 HYS	3600.00	2.00
013G12	100 Tat. 2nd	3600.00	2.00

Table 8. Counting schedules for the 2nd group of six archaeological samples within five days

Sample ID	Sample type	Counting time (s)	Geom.cm)
013G14	3rd Tat. 2 YS	3600.00	2.00
013G16	1st Tat. MRB	3600.00	2.00
013G18	2nd Tat. AHM 3	3600.00	2.00
013G20	45 Tat.1st	3600.00	2.00
013G22	400 Tat. 4th	3600.00	2.00
013G24	IAEA lake sediment	3600.00	2.00

Table 9. Nuclides of Interest and the Gamma ray Energy used for analysis

S/N	Element	Nuclides	Half-life	Eγ, (keV)
1	As	^{76}As	1574.4	559.1; 657.1
2	Au	^{198}Au	3880.8	411.8
3	Ba	^{131}Ba	16560.0	216.1; 373.2; 496.3
4	Br	^{82}Br	2118.0	698.4; 776.6; 1044.0
5	Ca	^{47}Ca	6531.8	1297.1
6	Ce	^{141}Ce	46814.4	145.4
7	Co	^{60}Co	2772383.4	1173.2; 1332.5
8	Cr	^{51}Cr	39888.0	320.1
9	Cs	^{134}Cs	1086126.3	569.3; 604.7; 795.8
10	Eu	^{152}Eu	7121622.4	964.9; 1112.1; 1408.1
11	Fe	^{59}Fe	64080.0	1099.2; 345.9; 482.2
12	Hf	^{181}Hf	61041.6	133.0; 815.8; 1596.5
13	K	^{42}K	741.6	1524.7
14	La	^{140}La	18360.0	328.8; 815.8;1596.5
15	Na	^{24}Na	897.6	1368.6
16	Nd	^{147}Nd	15811.2	92.1; 531.0
17	Rb	^{86}Rb	26827.2	1076.6
18	Sb	^{124}Sb	86688.0	602.7;722.8;1691.0
19	Sc	^{46}Sc	120715.2	889.3; 1120.5
20	Sm	^{153}Sm	2790.0	103.2
21	Sr	^{85}Sr	93369.6	514.0
22	Ta	^{182}Ta	164736.0	1189; 1221.1; 1231
23	Tb	^{160}Tb	104112.0	879.4; 966.2; 1178.0
24	Th	^{233}Pa	38836.8	312.0
25	Tm	^{170}Tm	185184.0	84.3
26	U	^{239}Np	3394.1	228.1;277.6
27	Yb	^{175}Yb	6026.4	282.5; 396.3
28	Zn	^{65}Zn	3511792.0	1115.5

Table 10. Measurement in IAEA SL-1 lake sediments and NIST coal Fly Ash 1633b for quality control

Nuclides	NIST coal fly Ash 1633b		IAEA-SL-1 lake sediment	
	k0-IAEA program, ppm	**Reference value, ppm**	***k0-IAEA program, ppm***	**Reference value, ppm**
As	135±0.1	136.2±2.6	32.4±3	24.7-30.5
Ba	704±4	709±27	642.2±131	586-692
Br*	1.9±1.1	2.9±1.5	5.2±2	NA
Ca	1501±5	1510±0.27	1.33±0.6	NA
Ce*	ND	190±6	98±5	100-134
Co*	39±2	50±3	18.9±0.5	18.3-21.3
Cr	194±6	198.2±4.7	104.7±8.0	95-113
Cs*	9±3	11±NA	6.8±1.0	6.1-7.9
Eu*	3±2.0	4.1±NA	2.2±1.1	1.1-2.1
Fe	7781±2	7780±23	64400±384	65700-69100
Hf	5.9±1.2	6.8±NA	4.6±0.7	3.6-4.8
K	1952±3	1950±30	11900±458	12400-16600
La*	95±1.9	94±NA	47.0±0.1	49.5-55.7
Na	204±3	201±3	1638.9±27	1600-1800
Nd*	ND	85±NA	45±6	NA
Rb*	ND	140±NA	106±19	102-124
Sb*	6.8±0.2	6±NA	1.3±0.3	1.19-1.43
Sc*	40.4±4	41±NA	16.3±0.03	16.2-18.4
Sm*	19±2	20±NA	8.2±0.12	6.74-9.76
Sr	1040±2	1041±14	NA	37-123
Ta*	1.7±2	1.8±NA	1.2±0.3	1.00-2.16
Tb*	2.1±0.5	2.6±NA	1.1±0.4	0.94-1.86
Th	24.9±2	25.7±1.3	13.5±0.7	13-15
Tm*	2.0±0.02	2.1±NA	2.5±0.9	NA
U	8.9±0.1	8.79±0.36	4.0±0.6	3.69-4.35
Yb*	7.5±0.3	7.6±NA	3.2±0.3	2.77-4.07
Zn*	211±2	210±NA	227.4±16	213-233

NA: not available, ND not detected
The interval presented in the reference value defines the 95% confidence level for IAEA lake sediment-SL-1
** = noncertified values by NIST coal Fly Ash 1633b*

Table 11. Results of trace elements concentration in ten sediment samples (A-J) within three days of cooling

Element	A (±2s)	B (±2s)	C (±2s)	D (±2s)	E (±2s)	F (±2s)	G (±2s)	H (±2s)	I (±2s)	J (±2s)
Na[b]	1.73	0.23	0.92	0.18	0.073	0.39	0.04	0.72	0.15	0.18
Mg[b]	1.14	0.64	ND	1.17	0.97	ND	0.57	0.70	0.02	0.01
Al[b]	6.91	8.46	11.10	10.3	10.03	6.60	7.60	8.12	0.01	0.03
Ti[b]	0.93	0.43	1.02	0.59	0.59	0.64	0.40	0.53	0.17	0.03
V[a]	122.00	75.2	155	96.3	67.4	43.3	62.6	60.7	21.0	1.02
K[b]	3.03	3.31	1.78	2.45	0.07	2.25	1.96	1.04	0.02	0.01
Mn[a]	658.00	201.00	787.00	227	118	105	97.3	662	192	209
Dy[a]	7.473	6.44	3.83	9.47	11.5	5.49	8.23	7.86	7.10	ND

[a] = indicate measurement in ppm, [b] =indicate measurement in percentage (%), (see table 1 and 2 for meaning of A to J)

Al was reported to be high with the value of 0.027% [±0.08] for sample J and 11.1% [±0.011] for sample C. Ti was seen to vary from 0.031 for clay sample J to 1.01 for clay sample C. However, the other elements V, Mn and Dy were obtained at trace level of ppm (mg/kg). in this context, V ranged from a value of 1.018 mg/kg [±0.013] for sample J to a value of 155 mg/kg [±0.09] for sample C, Mn varied from 97.3 mg/kg [±0.017] for sample G to 662 mg/kg [±0.011] for sample H. However, the value of Dy was 3.83 mg/kg [±0.012] for sample C and 11.5 mg/kg [±0.012] for sample E. Details of the distribution of the trace

elements along the ten analyzed samples are shown in Figs. 1 and 2 for A to J samples.

Indeed, six rare earth elements (REEs) were identified: Dy was obtained after a waiting period of three days from irradiation, however, Eu, Lu, Yb, La and Sm are obtained after five days from irradiations. Other trace heavy elements are obtained such as: Sc (4.75 to 14.6 ppm), Co (7.22 to 18.00 ppm), Cs (2.38 to 9.74 ppm), Ba (218.00 to 1112.00 ppm), U (0.53 to 2.48 ppm) Cr (29.20 to 80.80 ppm), Rb (91.50 to 154.00 ppm) and Yb (2.43 to 5.78 ppm). These results were reached within the statistical error of less than ±2 standard deviation for the ten samples from A to J (see Tables 1 and 2 for sample ID's).

Table 12. Results of trace elements concentration in ten sediment samples (A-J) within five days of cooling

Element	A (±2s)	B (±2s)	C (±2s)	D (±2s)	E (±2s)	F (±2s)	G (±2s)	H (±2s)	I (±2s)	J (±2s)
Sc[a]	6.75	14.60	9.52	18.80	10.40	9.25	4.75	10.60	10.80	8.62
Co [a]	6.22	21.50	10.20	23.20	8.93	18.00	7.22	11.90	8.76	7.17
Rb[a]	91.50	107.00	170.00	139.0	154.0	40.30	71.50	70.80	114.0	114.0
Cs[a]	9.74	2.38	3.55	3.95	5.33	4.78	8.74	6.60	5.36	3.85
Ba[a]	711.0	576.00	1112.0	642.0	700.0	218.0	411.0	308.0	495.0	510.0
Eu[a]	1.58	0.81	0.93	1.03	0.76	0.91	0.89	0.71	0.81	0.69
Lu[a]	1.79	2.14	2.61	2.37	0.57	0.61	1.59	0.64	0.45	0.35
Hf[a]	13.20	10.6	22.7	10.4	7.92	14.7	12.52	0.38	0.69	0.03
Ta[a]	1.79	2.14	2.61	2.37	1.81	1.83	1.09	1.12	0.78	1.01
Th[a]	10.08	8.90	9.87	6.67	1.96	8.42	5.47	6.62	1.61	1.38
Fe[b]	2.33	7.17	3.48	7.97	3.97	1.59	2.03	2.63	3.62	2.95
As[a]	BDL	0.64	BDL	BDL	0.88	1.12	0.02	11.63	1.75	1.09
Br[a]	1.18	0.49	2.31	2.77	2.01	1.21	1.08	1.32	1.58	1.32
La[a]	62.60	56.20	102.00	80.30	70.70	62.30	60.60	84.70	1.34	BDL
U[a]	2.48	2.45	2.00	2.47	0.71	2.57	2.55	2.45	0.53	0.64
Yb[a]	3.86	2.95	5.20	4.03	4.54	3.88	3.46	5.78	2.57	2.43
Cr[a]	29.20	74.80	56.10	75.40	63.50	80.80	BDL	47.30	54.40	44.50
Sm[a]	11.70	8.14	13.00	10.20	9.64	9.85	BDL	13.10	BDL	BDL
Yb[a]	3.86	2.95	5.20	4.03	4.54	3.88	BDL	5.78	2.57	2.43

BDL = Bellow detection limit

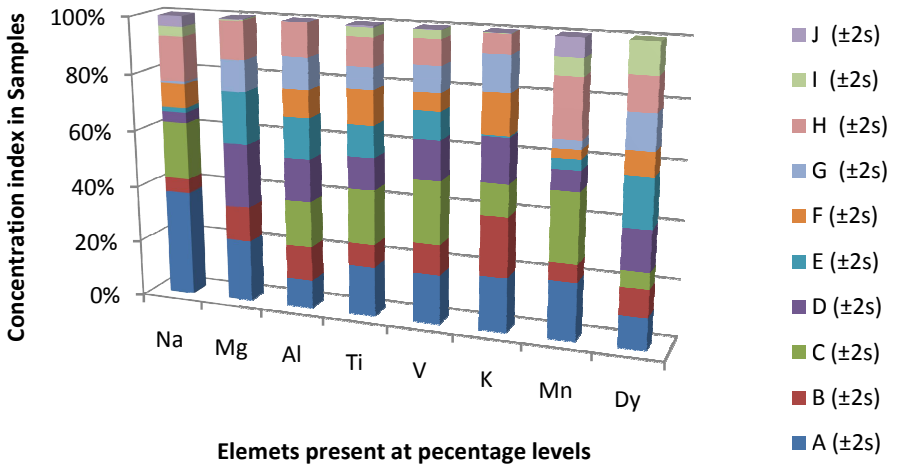

Fig. 1. Concentration index in samples per identified elements

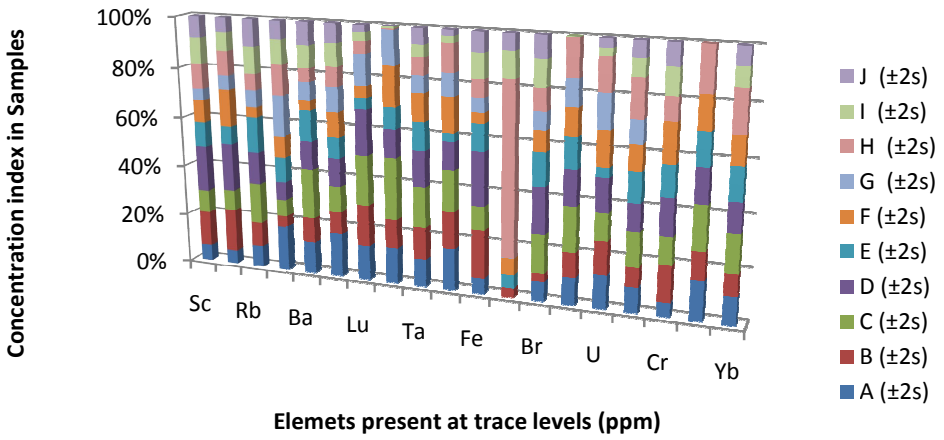

Fig. 2. Concentration index in samples per identified elements

5. CONCLUSION

A measurement of trace, heavy and REE elements has been analyzed with the aid of NIRR-1and k_0-IAEA program. The samples and SRMs were irradiated at a neutron flux setting of 5.0×10^{11} n cm^{-2} s^{-1} and a waiting period of one to five days. The use of the GEM-30195 coaxial detector was implemented and the concentration of twenty six elements including REE; Al, Mg, Ti, V, Na, K, Dy, Mn, Sc, Co, Rb, Cs, Ba, Eu, Lu, Hf, Ta, Th/Pa, Cr, Fe, As, Br, La, U/Np, Sm and Yb were determined quantitatively with an overall uncertainties generally low within a statistical value of less than ±2 standard deviation. The concentration of the SRMs obtained agreed well with the certified values.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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