Natural Radioactivity levels and Elemental Analysis of Cement by Gamma-Ray Spectrometer and Neutron Activation Analysis

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**Abstract**

Cement is considered a basic industry. For this reason, the current work involves the use of INAA for elemental analysis and Pollutant concentration in cement. The samples were collected from Saudi market. The samples were irradiated using the thermal neutrons "at the TRIGA Mainz research reactor" and at a neutron flux "of 7 x 10 11n/cms". Twenty elements were identified. The elements determined are: Na, K, Sc, Cr, Co, Ti, Mn, Fe, Ga, Sr, Sn, Ba, Cs, Ce, Sm, Yb, Lu, Hf, Th and U. The concentrations of natural radionuclides 232Th, 226Ra and 40K were also measured. The average values for 226Ra, 232Th and 40K are 35.60 , 43.17, 82.08 Bq·kg\_1 for Portland cement and 28.53, 43.46, 67.38 Bq·kg\_1 for white cement. The radiation hazard indices such as radium equivalent activities, effective dose rate, and the external hazard indices have been computed. The obtained results were compared with related studies carried out in other countries and with the UNSCEAR reports.

***Keywords*:** Elemental analysis – Natural Radioactivity - Hazard indices - Cement- INAA- EDXRF - Triga Mainz

***Introduction***

Great attention has been paid to determining radionuclides concentration in cement in many countries(Baykara, Karatepe, and Doğru 2011; Rahman, Rafique, and Jabbar 2013; Uosif 2014; Sharma et al. 2015).Various analytical techniques have been utilized in the elemental analysis of Portland cement. Common among them are X-ray fluorescence XRF, WDXRF, EDXRF, Atomic Absorption and INAA (Mujahedeen 2001; Kurudirek, Aygun, and Erzeneoğlu 2010). Neutron activation analysis is a sensitive analytical technique useful for performing both qualitative and quantitative multi-element analysis of major, minor and trace elements in samples from almost every

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conceivable field of scientific or technical interest. “For many elements and applications, the NAA offers

sensitivities that are superior to that possible by other methods of the order of parts per billion or better. Also

, because of its accuracy and reliability, the NAA is recognized as the reference method of choice when new procedures are being developed or when other methods yield results that do not agree”(El-Taher and Abdelhalim 2014a, 2014b).The aim of the present work is to analyze major, minor and trace elements in cement as well as to measure the concentration of the natural radionuclides and radiation level using NAA and a gamma spectrometer to check the quality control also to evaluate the reliability of these methods in the daily analysis of cement products (El-Taher et al. 2004).

***Material and Methods***

***Samples preparation***

Portland and white cement were collected for investigation from Saudi market. Each of the samples is Weighing about 1 kg and then dried in an oven at about 1050c to make sure that all the moisture has been removed. For elemental analysis using instrumental neutron activation analysis: the powder samples were sieved through a set of standard sieves with diameters ranged of between 63-125 mm, and an electric shaker was used to obtain homogeneous samples.Then, the irradiation of the samples by using thermal neutrons, concerning the measurement of the natural radioactivity: Each sample was grinded, homogenized. The samples were weighed, packed-sealed in a polyethylene Marinelli beakers, of 350cm3 volume each and then stored for four weeks to attain secular equilibrium with the short-lived daughters of 232Th and 226Ra and their long-lived parent radionuclides (Eštoková and Palaščáková 2013).The activity concentrations of radionuclides were determined from the significant average energy lines of 609.3, 1120.3 and 1764.5 keV (214Bi),352.9 keV (214Pb) for .226Ra , 1460.7 keV for 40K and 968.9, 338.4 and 9,11.1 keV (228Ac) for 232Th series (Raghu *et a*l. 2015)

***Instrumentation and irradiations***

One hundred mg of powder cement samples was filled in Polyethylene capsules and then irradiated with a Dolerite WSE and Microgabro PMS standard reference material with thermal neutrons "at the University of Mainz Triga research reactor (100 kWth) with a flux of 7x1011 n/cm2s". The concentration of the elements determined in the irradiated samples was quantitatively specified by comparison with the activities of the reference materials (El-Taher and Abdelhalim 2014a; Stamatelatos et al. 2010). After appropriate cooling times, the data were collected to conduct different measurements (Report 1989). The irradiation conditions for the elements determined were shown in Table1. The measuring of activity concentration for radionuclide in studying samples was defined using gamma-ray spectrometer system by a HPGe detector with an electronic circuit. The HPGe detector has equipped with specifications as a follow: energy resolution (FWHM) is 1.70 keV at 1.33 MeV 60Co, Peak to Compton ratio 60Co is 65.2, relative efficiency is 29.2 at 1.33 MeV 60Co. The Inter-gamma Software that generated by the Inter-technique “Deutschland GmbH, Mainz, Germany (El-Taher 2010a), accomplished the analysis of results. In all measurements, the electronic dead time is less than 10 % and the Inter-Gamma software performs the correction automatically (Funtua et al. 2012).

***Estimation of radiological dose and hazard indices***

**Radium equivalent activity(Raeq):**

The radium equivalent activity (Raeq) values in Bq/kg were obtained by using the following equation:

*Raeq = CRa + CTh ×1.43 + CK×0.077 (1)*

Where, Ck, CTh and CRa are the activity concentrations of 40K, 232Th and 226Ra in samples, respectively. The definition is based on the supposition that 130 Bq/kg of 40K, 7 Bq/kg of 232Th and 10 Bq/kg of 226Ra are created the same gamma radiation exposure dose (Beretka and Mathew 1985).

**Absorbed dose rate (D):**

The absorbed dose rate in the air due to radionuclides at 1 m above the ground surface for the uniform distribution of (226Ra, 232Th, and 40K) was calculated according to guidelines supplied from UNSCEAR.

*D = CRa ×0.462+ CTh× 0.604 + CK×0.0417 (2*)

Where, 0.462, 0.0417 and 0.604 nGy h−1 per Bq/kg were the conversion factors corresponding to 226Ra (238U-series), 40K and 232Th (UNSCEAR 1993, 2000).

**External hazard index (Hex):**

The recommended value of absorbed is 1.5 mSv y-1, (ICRP. 1990). To limit the radiation dose value to this rate, by the conventional model suggest based on infinitely thick walls, without doors and windows (Krieger 1981) to serve as a standard for the computation of index defined as external hazard index Hex from the following relation:

*Hex = CRa / 740 +CTh/ 520 +CK/9620  1 (3)*

***Results and Discussion***

The average concentration values of the elements determined in cement samples in four irradiation cycles are shown in Table 2. Twenty elements were identified: Na, K, Sc, Cr, Co, Ti, Mn, Fe, Ga, Sr, Sn, Ba, Cs, Ce, Sm, Yb, Lu, Hf, Th and U . The concentrations of all elements were expressed in μg/g except for Na, Mn, Fe, Ti and K were given in g/kg. The concentration of determining elements was specified using multiple activities produced by (nγ) reactions, since, some of the radionuclides committed to exhibit more than one obvious and distinct gamma line. In all other situations, the elements were measured by their most distinctive peaks, with lowest statistical errors, free of interference, with lowest statistical errors, and free of interference. The measurement accuracy has been estimated using the PMS and WSE analysis, for the standard reference materials. From the obtained results, we can say that INAA is an effective and successful mean to supply valuable data for cement samples with a satisfying precision. The accuracy for most elements in present results are in the range of 10 % of the reference values, and a good precision has been shown in most results (El-Taher 2010a, 2010b, 2010c).

The rare earth elements determined are Ce, Sm, Yb and Lu. The selection of photopeaks for the analysis is briefly discussed below for each element. For cerium, the photopeak of 141Ce at 145 keV was used. For samarium, the isotope153 Sm is used. Ytterbium can be determined using the 198 keV peak of 169 Yb. The 396 keV peak cannot be resolved from nearby peaks of 152Eu 383 keV and 233Pa 381 keV. For lutetium, the high abundance peak at 208 keV of 177m Lu was used. The elemental concentration of uranium via U and thorium via Th in clay samples. The activation converts U and Th into Np and Pa, respectively, by neutron capture and successive β-decay (El-Taher 2010a, 2010b, 2010c).



U (n, γ ) U ------ Np E= 106 keV



Th (n, γ) Th ----- Pa E= 312 keV



The results of natural radionuclides concentration in Portland and white cement are presented in Table 3. The average values for 226Ra, 232Th and 40K are 35.60 , 43.17, 82.08 Bq·kg\_1 for Portland cement and 28.53, 43.46, 67.38 Bq·kg\_1 for white cement. The obtained results show that the radionuclide concentrations in the Portland and white cement are below the world averages for building materials which are 50, 50 and 500 (Bq.kg-1) for 226Ra, 232Th and 40K, respectively (UNSCEAR 2000). Table 4 shows a comparison between the average concentration values from the present study with similar studies performed in other countries. From Table 4, the activity concentrations of 226Ra, 232Th and 40K for Portland and white cement were comparable with the results of similar studies undertaken in other countries. The activity concentration in Portland cement changes from one country to another with consideration of various materials used in cement production. The contents of 226Ra, 232Th and 40K in cement materials depend on their chemical composition that related to geological source and geochemical characteristics. “It is important to point out that these values are not representative values of the countries mentioned but are specific to the regions from where the samples were collected. Radium, thorium, and potassium are not uniformly distributed in soil or rocks, from which building materials are derived, but the radioactivity varies, often greatly, over a distance of some meters.”(El-Taher 2010c) The average activity concentrations of 232U, 232Th and 40K in the cement samples under study are given in Figure 1.

Table 5, gives the estimated radium equivalent activity, dose rate, external hazard index and representative level index due to natural gamma emitters as measured in Portland and white cement under study. From this Table, for all samples, we can indicate the following: - The Raeq values varying from 90.50 to 145.13 Bq kg-1with a mean value of 99.24 Bqkg-1. These values are lower than the maximum permissible value of 370 Bq kg-1. The absorbed dose rate varying from 49.02 to 63.73 nGy /h with a mean value of 51.87 nGy /h. These values are lower than the maximum permissible value of 55 nGyh-1 (UNSCEAR 2000). The calculated external hazard values for cement samples varies from 0.17 to 0.29 with a mean value of 0.23. All the cement samples have values lower than unity. Based on the obtained results of radium equivalent activity, representative level index and external hazard indices, one can conclude that there is no health hazard from the using of this cement in construction. Figure 2 showed the radium equivalent and absorbed dose of the present cement samples.

***Conclusion***

Twenty elements were quantitatively determined in cement samples collected from the local market in Saudi Arabia. The elements determined are: Na, K, Sc, Cr, Co, Ti, Mn, Fe, Ga, Sr, Sn, Ba, Cs, Ce, Sm, Yb, Lu, Hf, Th and U. From the obtained findings, we can say that INAA is an effective and useful tool to provide a good data for cement samples. The average values for 226Ra, 232Th and 40K are 35.60, 43.17, 82.08 Bq·kg\_1 for Portland cement and 28.53, 43.46, 67.38 Bq·kg\_1 for white cement and were less than the recommended levels of UNSCEAR data.

## Acknowledgement

The authors acknowledge, with thanks the Deanship of Scientific Research (DSR), King Abdul Aziz University, Jeddah for technical and financial support under grant No. (372- 536 –D- 1435).

Table (1): Irradiation cycles and determined elements

|  |  |  |  |
| --- | --- | --- | --- |
| Determined elements | Measuring time | Cooling  time | Irradiation time |
| Ti | 4m | 5m | 1 m |
| Mn, Sr | 15m | 1h | 5 m |
| Mn, K, Ga, Sm, U | 1h | 2d | 6 h |
| Sc, Cr, Fe, Co, Zn, Sn, Ba, Cs, Ce, Yb, Lu, Hf, Th | 8h | 14d | 6 h |

Table 2: The elemental content of cement using INAA.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| White cement | Portland  Cement | T1/2 | Eγ, keV | Isotope | Element |
| 0.7 | 10.04 | 14.96 h | 1368.6 | Na-24 | Na% |
| --- | 1.17 | 12.4 h | 1524 | K-42 | K % |
| 2.35 | --- | 83.8 d | 1120 | Sc-46 | Sc ppm |
| 34.8 | 2.3 | 27.7 d | 320 | Cr-51 | Cr ppm |
| 0.45 | 0.45 | 3.75 m | 320 | Ti-51 | Ti % |
| 0.001 | 0.019 | 2.59 h | 847 | Mn-56 | Mn % |
| 0.008 | ---- | 44.5 d | 1099 | Fe-59 | Fe % |
| 0.02 | --- | 5.27 y | 1173&1332 | Co-60 | Co ppm |
| 5.63 | ---- | 14.1 d | 834 | Ga-72 | Ga ppm |
| 247 | 179 | 2.81h | 388 | Sr-87 | Sr ppm |
| 1.63 | 0.90 | 13.6 d | 159 | Sn-117 | Sn ppm |
| 103 | --- | 11.5 d | 496 | Ba-131 | Ba ppm |
| --- | 0.014 | 2 y | 605 | Cs-134 | Cs ppm |
| 8.17 | 1.30 | 32.5 d | 145 | Ce-141 | Ce ppm |
| 0.84 | 0.3 | 46.2 | 103 | Sm-153 | Sm ppm |
| 0.71 | --- | 32d | 198 | Yb-169 | Yb ppm |
| 0.10 | ---- | 161d | 208 | Lu-177 | Lu ppm |
| 3.73 | 0.18 | 42.39d | 482 | Hf-182 | Hf ppm |
| 2.48 | 0.13 | 27d | 312 | Pa-233 | Th ppm |
| --- | 0.69 | 2.35d | 106 | Np-239 | U ppm |

Table 3: The activities of 226Ra, 232Th and 40K ( Bq Kg~~-~~1) of cement

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample  number | Sample  Name | 226Ra | 232Th | 40K |
| 1 | Portland | 18.09±3.81 | 8.24±0.49 | 76.86±3.84 |
| 2 | 41.89±5.11 | 47.55±2.39 | 89.14±4.45 |
| 3 | 36.22±5.06 | 45.94±2.30 | 86.64±4.33 |
| 4 | 37.10±3.98 | 71.65±3.58 | 79.32±3.96 |
| 5 | 44.71±4.08 | 42.45±2.12 | 78.42±3.92 |
| **Average** |  | **35.60±4.41** | **43.17±2.18** | **82.08±4.10** |
| 6 | White | 34.57±4.51 | 43.15±2.16 | 74.17±3.70 |
| 7 | 25.14±3.33 | 44.25±2.22 | 56.63±2.83 |
| 8 | 31.04±3.96 | 44.72±2.24 | 71.42±3.57 |
| 9 | 27.29±3.32 | 42.45±2.13 | 66.613±3.33 |
| 10 | 24.61±3.63 | 42.74±2.14 | 68.05±3.40 |
| **Average** | **28.53±3.75** | **43.46±2.18** | **67.38±3.36** |

Figure.1 Comparison between the average activities of 226Ra, 232Th and 40K of Portland and white

cement samples under investigation.

Figure.2 Average absorbed dose rate (nGy/h) and Radium equivalent (Bq/Kg)

for Portland and white cement samples

Table 4 Comparison the activities of 226Ra, 232Th, 40K and (Ra)eq in cement from worldwide

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Material | Country | Activity concentration | | | Ra**eq** | Références |
| 226Ra | 232Th | 40K |
| Portland cement | India | 19 | 35 | 406 | 60.8-121 | (Sharma et al. 2015) |
| China | 118.7 | 36.1 | 444.5 | 154.4 | (Lu, Chao, and Yang 2014) |
| Egypt | 33.8 | 61.8 | 89.0 | 129 | (Uosif 2014) |
| Tanzania | 46 | 28 | 228 | 103.60 | (Amasi et al. 2014) |
| Nigeria | 30.2 | 24.6 | 251.3 | 84.7 | (Agbalagba, Osakwe, and Olarinoye 2014) |
| Malaysia | 34.7 | 32.9 | 190.6 | 96.42 | (Majid et al. 2013) |
| Pakistan | 37 | 28 | 200 | 92.0 | (Rahman, Rafique, and Jabbar 2013) |
| Turkey | 24.7 | 20.7 | 2493.1 | 246.1 | (Baykara, Karatepe, and Doğru 2011) |
| Saudi Arabia | 35.60 | 43.17 | 82.08 | 103.09 | Present work |
| White cement | Egypt | 40.7 | 65.5 | 77.9 | 140.3 | (Uosif 2014) |
| Nigeria | 41.9 | 30.1 | 340.2 | 111.1 | (Agbalagba, Osakwe, and Olarinoye 2014) |
| Iraq | 31.0 | 3.8 | 10.2 | 37. 2 | (Ali 2012) |
| Turkey | 12.5 | 2.7 | 1141.9 | 104.2 | (Baykara, Karatepe, and Doğru 2011) |
| Saudi Arabia | 28.53 | 43.46 | 67.38 | 95.40 | Present work |

Table 5: The radiation hazard parameters of cement

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample  number | Types of  cement | Raeq  (Bq/kg) | D,  (nGy/h) | Hex |
| 1 | Portland | 115.27 | 46.54 | 0.24 |
| 2 | 116.13 | 51.79 | 0.20 |
| 3 | 107.99 | 48.09 | 0.19 |
| 4 | 145.13 | 63.73 | 0.29 |
| 5 | 110.91 | 49.57 | 0.18 |
| **Average** | **119.09** | **51.94** | **0.22** |
| 1 | White | 101.47 | 45.12 | 0.18 |
| 2 | 92.40 | 40.71 | 0.18 |
| 3 | 99.99 | 44.33 | 0.18 |
| 4 | 92.66 | 41.03 | 0.17 |
| 5 | 90.50 | 40.02 | 0.17 |
| **Average** | **95.40** | **42.24** | **0.18** |

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