COPPER EXTRACTION AND RADON EXAMINATION IN SELECTED MINE SAMPLES

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Abstract

The main objective of this study was to analyze the elemental composition of three chosen samples, with a specific focus on extracting copper from a rock sample obtained from the Letpadaung copper mine. Additionally, the research investigated the potential health risks for mine workers and assessed radon concentrations in these mine samples using LR-115 Solid State Nuclear Track Detectors (SSNTDs). The LR-115 type II detectors were employed to explore radon in various samples: coal from the Thitchauk coal mine, fly ash from the Tigyit power plant, and rock samples from the Letpadaung copper mine. The tracks observed through an optical microscope, confirmed the presence of radon as an alpha emitter in some samples. The annual effective radiation dose of each sample determined was 0.6531 mSv/y for fly ash sample and 0.4533 mSv/y for coal samples. However, all annual effective doses for the samples were below the international reference level of 3-10 mSv/y recommended by the International Commission on Radiological Protection (ICRP). It is crucial to inform individual working in power plants about the potential health risks associated with radon exposure. Moreover, elemental composition analysis using ED XRF data revealed the presence of various elements in the samples. Furthermore, copper extraction from the rock sample was carried out through a metal displacement reaction and electrolysis, resulting in a copper content of 2.07 %.

Keywords: LR-115 type II detectors, radon, coal, fly ash, rock, and copper

Introduction

Naturally occurring radioactivity is ubiquitous in our environment, with people continuously exposed to various sources such as solar radiation, cosmic radiation, telluric radiation, and internal radiation from within our bodies. Coal contains natural radionuclides primarily from the U-238 and Th-232 decay chains, existing in trace amounts and considered in equilibrium with their parent radionuclides (AboJassim and Shiitake, 2013). Low-quality coal, like lignite, has been reported to contain Ra-226 concentrations ranging from 310 to 350 Bq/kg (Takahashi *et al.*, 2021). When coal is burned and transformed into fly ash, uranium and thorium concentrations can increase by up to 10 times their original levels.

Fly ash disposal in landfills and abandoned sites, including mines and quarries, poses potential risks of groundwater contamination for people residing in those areas (Abojassim and Husain, 2015). Beyond inhalation, solid fallout is an additional radiation hazard, leading to elevated concentrations of natural radionuclides in surface soils around power plants. Uranium leaching from fly ash into soil and water at disposal sites can impact cropland and, consequently, food (Barooah *et al.*, 2011).

Radon, a naturally occurring inert radioactive gas with no taste, colour, or odour and a half-life of 3.83 days, can dissolve in water, enabling its transport over considerable distances through soil. In specific locations, radon concentrations may pose a significant health risk.

Copper, a widely utilized metal in electrical, electronics, construction, and manufacturing sectors, undergoes extraction through two main methods: pyrometallurgy and hydrometallurgy. Pyrometallurgy is primarily employed for sulphide flotation concentrates on an industrial scale, economically viable when dealing with copper-rich ores. In contrast, hydrometallurgy is a widely used method for copper extraction on a global scale.

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Radon exploration in the building materials by using LR-115 detector has been studied by Win Ko *et al*. (2021). This work focuses on the investigation of the elemental content from three mine samples and the extraction of copper from the Letpadaung copper mine. Furthermore, the examination of the health hazards for mine workers and the radon concentration of these mine samples using LR-115 as Solid-State Nuclear Track Detectors (SSNTDs).

Materials and Methods

Detection of Alpha Particles via Radon in Some Selected Samples

In this work, LR-115 type II Solid State Nuclear Track Detectors were used for measuring alpha particles via radon in coal samples from the Thitchauk coal mine, Kalewa Township, Sagaing Region, fly ash samples from the Tigyit power plant, Shan State, and rock samples from the Letpadaung copper mine, Salingyi Township, Sagaing Region.

Each sample (100 g) was placed in the cylindrical 'Can' as shown in Figure 1. The LR-115 type II detector was fixed on the top inside of the 'Can' for six months (180 days). The plastic 'Can' is 7.5 cm in height and 8.0 cm in diameter. During this time, the alpha particles from radon and its daughter would leave tracks on the detector. The LR-115 type II detector was removed from the plastic 'Can' and etched chemically in a 10 % NaOH solution at 60 °C for 90 min in an oven. The etched tracks on the detectors were scanned using an optical microscope at 200 magnifications (Win Ko and Hnin Hnin Than, 2022).

The measured track density was converted into Bq/m^3 by using a calibration factor (0.21 tracks/cm^{2}d = Bq/m^3) determined by the National Institute of Radiological Science (NIRS), Vietnam (Nguyen *et al*., 2016).

(a) Coal (b) Fly ash (c) Rock

Figure 1. Detection of alpha particles via radon in the selected sample

Extraction of Copper from Letpadaung Copper Mine Rock Samples

Acid leaching

The copper mine rock samples were crushed into small pieces or powder to increase the surface area for better contact with the acid. Sulphuric acid was commonly used for copper leaching due to its effectiveness and cost-efficiency. A suitable reactor or vessel was set up to conduct the leaching process. The appropriate amount of acid was decanted into the vessel to create the desired concentration of the acid solution. The temperature and time were controlled in the acid-leaching process. Higher temperatures and longer leaching times enhanced copper extraction, but safety considerations should be taken into account. The acid to ore ratio is an essential parameter. The appropriate ratio depends on the ore composition and the desired copper extraction efficiency. It is necessary for good copper extraction to have two days' percolation. The solid residue (copper-depleted rock) was separated from the liquid solution (leachate) using filtration and centrifugation techniques. The resulting solution, rich in copper sulphate and sulphuric acid, was collected in a beaker. Consequently, the copper sulphate solution was carried out by using displacement reaction and electrolysis.

Displacement reaction of copper (II) sulphate solution

The reactivity between two metals can be compared using displacement reactions in salt solutions of one of the metals. This is easily seen as the more reactive metal slowly disappears from the solution, displacing the less reactive metal. Zinc is a reactive metal and can displace copper from copper (II) sulphate solution. The blue colour of the $CuSO_4$ solution fades as a colourless zinc sulphate solution is formed.

Electrolysis

Leach liquors (copper (II) sulphate) were used from the acid leaching of the Letpadaung copper mine. During the electrolysis of copper sulphate with copper electrodes, copper was deposited on the cathode and the same amount of copper was removed from the anode. It was done for a good amount of copper to have two days of electrolysis. In this process, a good amount of copper was produced from the Letpadaung copper mine. This result is shown in Table 4.

Results and Discussion

Elemental Analysis of Coal, Fly Ash and Rock Samples by ED XRF

The results of the elemental analysis of coal, fly ash, and rock samples are shown in Table 1. The coal sample contained Fe (51.275 %), Ca (24.727 %), and S (15.192 %). In the fly ash sample, Si (41.027 %), Ca (26.739 %), Al (17.251 %), and U (0.054 %) were detected. The rock sample showed the presence of Si (34.226 %), Cu (27.930 %), S (18.658 %), and Fe (12.072 %).

Table 1. Relative Abundance of Some Elements in Coal, Fly Ash, and Rock Samples by ED XRF

No.	Symbol	Relative Abundance (%)		
		Coal	Fly Ash	Rock
1	Si	-	41.027	34.226
2	Ca	24.727	26.739	0.533
3	Al	-	17.251	-
4	Fe	51.275	7.924	12.072
5	K	0.899	3.620	5.707
6	S	15.192	1.712	18.658
7	Ti	1.155	1.126	0.680
8	V	-	0.128	0.037
9	Mo	-	0.091	-
10	Mn	0.161	0.064	0.032
11	U	-	0.054	-
12	Cr	0.173	0.046	-
13	Zr	-	0.044	0.023
14	As	-	0.042	-
15	Cu	3.484	0.033	27.930
16	Zn	0.258	0.024	-

No.	Symbol	Relative Abundance (%)		
		Coal	Fly Ash	Rock
17	Rb	-	0.023	-
18	Sr	1.629	0.022	0.101
19	Ni	1.048	0.020	-
20	Y	-	0.010	-

From the ED XRF data, uranium was found to be present in the fly ash samples. According to literature, the natural radionuclides present in coal consist mostly of members of the U-238 and Th-232 decay chains. Thus, radon and its decay products will be found in the fly ash samples.

Application of LR-115 Type II Film Detectors for Radon Measurement at Some Selected Samples

The LR-115 type II detector is better at alpha detection. Hence, it was used for the observation of alpha particles via radon-emitting sites such as coal, fly ash, and rock samples. From the study of microscope images, LR-115 type II can detect alpha. An LR-115 type II detector was used for radon level measurement in these selected samples. Radon activity, radon exhalation rate, and radon concentration in some selected samples were measured. Alpha radiation tracks can be detected by using LR-115 type II with an active layer. The photomicrographs for the revelation of alpha particle tracks observed in LR detectors placed at the top of the coal samples are shown in figure 3. The track density, radon activity, radon exhalation rate, radon concentration, and annual effective dose were calculated by a computer Excel program and the results are described in Table 2.

The average track density of coal samples was found to be 105.2542 track/cm^{2}d. The annual effective dose equivalent rate for the Thitchauk coal mine workers lies within the range of 0.1219 to 0.9748 mSv/y, i.e., lies within the intervention limit (3-10 mSv/y) for mine workers. Although the mine workers are safe from health hazards from radon, people staying around the coal mine should be aware of the health risks from radon exposure.

Figure 4 shows the photomicrographs of the revelation of alpha particles tracks observed LR detectors placed at the top of the fly ash samples from Table 3, the average track density of fly ash samples was found 151.6566 tracks/cm^{2}d. The annual effective dose of fly ash samples for the Tigyit power plant workers lies within the range of 0.4265 to 1.0480 mSv/y. According to the ICRP recommendations, the intervention limit for workplaces is 3–10 mSv/y. Therefore, the mean value of annual effective dose (0.6531 mSv/y) of fly ash lies within the intervention limit for workers. People staying around the Tigyit power plant are not at risk of radon exposure.

Figure 5 shows the photomicrographs of the revelation of alpha particles tracks observed LR detectors placed at the top of the rock samples from Table 4, the average track density of rock samples was found 36.2165 tracks/cm^{2}d. Therefore, the mean annual effective dose (0.2418 mSv/y) of rock samples lies within the intervention limit for workers. People staying around the mine are not at risk of radon exposure.

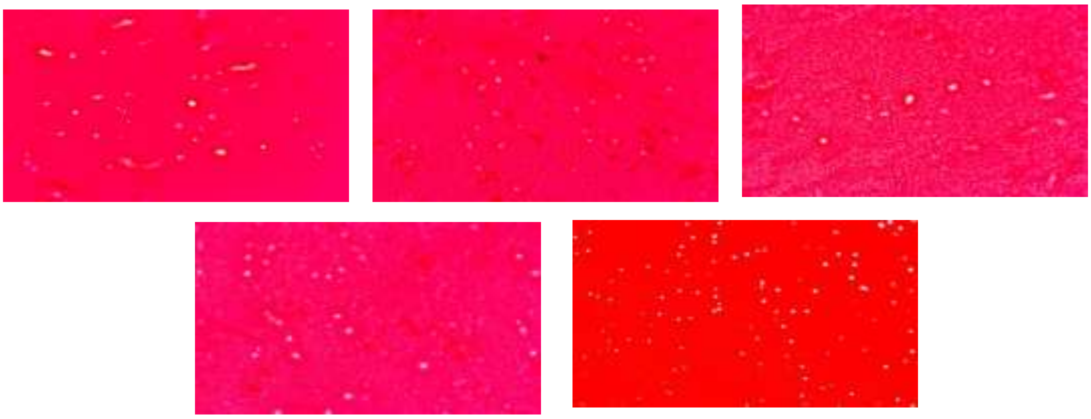


Figure 3. Photomicrographs for the revelation of the alpha particle tracks observed in five LR-115 detectors placed at the top of the coal samples

Table 2. Measurement of Track Density, Radon Activity, Radon Concentration, and Annual Effective Dose in Coal Samples

Detectors	Track Density (tracks/cm^{2}d)	Radon Activity (Bq/m^3)	Radon Concentration (Bq/m^3)	Annual Effective Dose (mSv/y)
1	28.2941	134.7340	4.3401	0.1219
2	70.7354	336.8351	10.8503	0.3046
3	82.0530	390.7287	12.5864	0.3534
4	118.8354	565.8829	18.2285	0.5118
5	226.3532	1077.8722	34.7210	0.9748
Mean Value ± s	105.2542 ± 75.0035	501.2106 ± 357.1595	16.1453 ± 11.5050	0.4533 ±0.3229

s = standard deviation
* ICRP reference level of radon concentration = 200–600 Bq/m^3
** ICRP reference level of annual effective dose = 3–10 mSv/y

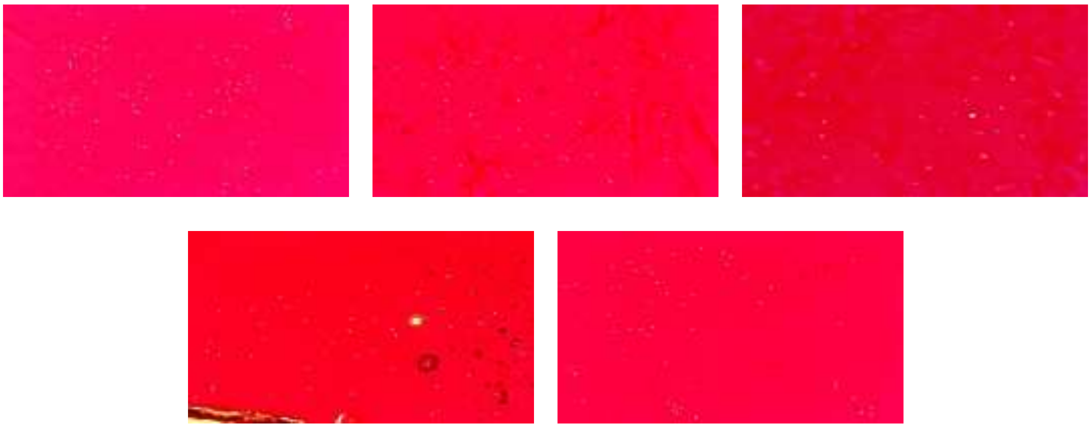


Figure 4. Photomicrographs for the revelation of the alpha particle tracks observed in five LR-115 detectors placed at the top of the fly ash samples

Table 3. Measurement of Track Density, Radon Activity, Radon Concentration, and Annual Effective Dose in Fly Ash Samples

Detectors	Track Density (tracks/cm²d)	Radon Activity (Bq/m³)	Radon Concentration (Bq/m³)	Annual Effective Dose (mSv/y)
1	99.0295	471.5691	15.1904	0.4265
2	127.3237	606.3031	19.5305	0.5484
3	141.4707	673.6701	21.7006	0.6093
4	147.1296	700.6169	22.5686	0.6336
5	243.3297	1158.7126	37.3250	1.0480
Mean Value ± s	151.6566 ±54.5204	722.1744 ±259.6209	23.2631 ±8.3631	0.6531 ±0.2348

s = standard deviation
* ICRP reference level of radon concentration = 200–600 Bq/m³
** ICRP reference level of annual effective dose = 3–10 mSv/y

Figure 5. Photomicrographs for the revelation of the alpha particle tracks observed in five LR-115 detectors placed at the top of the rock samples

Table 4. Measurement of Track Density, Radon Activity, Radon Concentration, and Annual Effective Dose in Rock Samples

Detectors	Track Density (tracks/cm²d)	Radon Activity (Bq/m³)	Radon Concentration (Bq/m³)	Annual Effective Dose (mSv/y)
1	19.8059	94.3138	4.7095	0.1322
2	36.7824	175.1542	8.7463	0.2456
3	42.4412	202.1010	10.0919	0.2833
4	39.6118	188.6276	9.4191	0.2645
5	42.4412	202.1010	10.0919	0.2833
Mean Value ± s	36.2165 ± 9.4690	172.4596 ± 45.0906	8.6117 ± 2.2516	0.2418 ± 0.0632

s = standard deviation
* ICRP reference level of radon concentration = 200–600 Bq/m³
** ICRP reference level of annual effective dose = 3–10 mSv/y

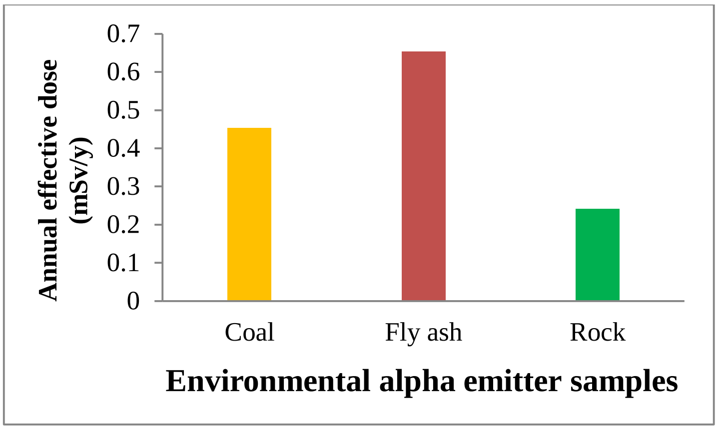
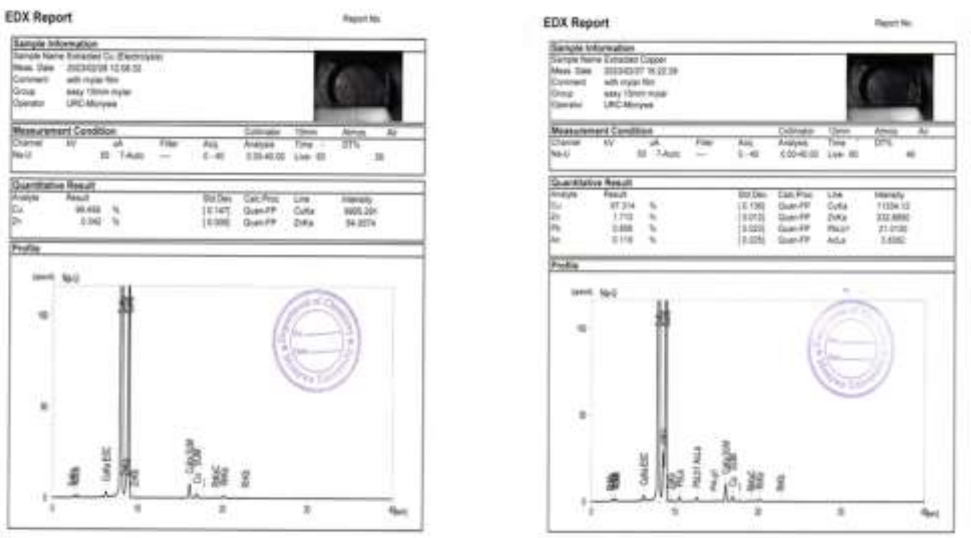


Figure 6. The annual effective doses of environmental alpha-emitter samples

According to Figure 6, the annual effective doses of fly ash samples are higher than the others. The by-products of fly ash from thermal power plants have thus become a subject of worldwide interest in recent years because they can be used in the production of cement, clay ash bricks, and cellular concrete blocks, as well as in the construction of roads and rail embankments and similar applications. Therefore, the workers should be aware of the health risks from radon exposure.

Extraction of Copper from Letpadaung Copper Mine Rock Samples

The copper content (27.930 %) of the rock samples was determined by an ED XRF analysis (Figure 7). Copper extraction (2.6324 g/200g) from the rock ores was successfully carried out after two days of electrolysis. Furthermore, the displacement reaction of metal was used to extract copper (18.100 g/800g from the rock ores. The results from Table 4 shows that a higher copper content (2.07324 %) was obtained in the copper extraction process.



(a) Electrolysis (b) Displacement reaction of metal

Figure 7. Pure copper content (%) by using ED XRF analysis

Table 5. The Copper Content of the Rock Samples from the Lapadaung Copper Mine

No.	Method	Extracted Copper (g)	Pure copper (%)	Copper content (%)
1.	electrolysis	2.6324	99.458	2.07324
2.	displacement reaction of metal	18.100	97.314	

From ED XRF data, the extracted copper contents by electrolysis and displacement reaction of metal were found to be 99.458% and 97.314%, respectively. During electrolysis, pure copper (99.458 % Cu) was deposited on the cathode plates, along with impurities that are soluble and fall to the bottom of the cell as anode mud or sludge (Figure 8).

Figure 8. Extracted copper from the Letpadaung copper mine rock samples

Conclusion

This study concludes that the LR-115 type II film detector successfully detected radon concentration in all samples (coal, fly ash, and rock) due to alpha-emitting radioactive substances. Analysis of ED XRF data revealed the presence of uranium in fly ash samples, indicating the likelihood of radon and its decay products in both coal and fly ash samples. The annual effective doses in coal, fly ash, and rock samples were found to be 0.4533, 0.6531, and 0.2416 mSv/y, respectively, adhering to the international reference level (3–10 mSv/y) set by the ICRP. Despite this, individuals residing in proximity to mines and power plants should remain vigilant regarding potential radon exposure. ED XRF analysis of rock samples identified the presence of copper, sulphur, and iron. Through metal displacement reactions, copper was produced with 97.314 % purity whereas electrolysis produced 99.458% purity. This extracted copper holds potential applications in the production of wires, plates, tubes, and other copper-based products, showcasing the utility of copper displacement reactions for MSMEs (micro, small, and medium-sized enterprises). The insights from this research contribute valuable information to the economic considerations of regional economies.

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