Radiological Implications of Selected Fertilizers (0-0-60)

B. Billa[1]; M. Beitollahi[3]; S. Adzanu[2]; and J. Adjaye[2]

1. Porters Chapel Academy, Vicksburg, MS 39183
2. Alcorn State University, Lorman, MS 39096
3. University of Utah, Salt Lake City, UT 84132

Abstract

Fertilizers are part of farming industry and play a major role in improvement of plants growth and enhancement of crop yields. One of the essential elements, potassium, helps in root growth and drought resistance of plants. Depending on soils fertility, farmers tend to provide potassium in the form of potash fertilizer which is derived from potash rock cored from earth's crust. Rocks derived from the earth's crust consist of trace quantities of Naturally Occurring Radioactive Materials (NORM) and their concentrations significantly vary based on rock type, geographical location, and geological formation. Potash is a commonly used fertilizer derived from potash rock and to increase concentration of potassium, manufacturers increase percentage of potash which can eventually enhance radioactive concentrations (specifically K-40) in fertilizers. To exactly estimate and experimentally verify the levels of radioactive K-40 in selected fertilizers (0-0-60), a study was performed on fertilizers available in local market. K- 40 was theoretically estimated by considering the half-life; molar mass; and decay constant while experimental studies were carried out by performing gamma-spectroscopy. Obtained results for radioactivity concentrations of K-40 from theoretical estimation and gamma spectroscopy are 15, 110 and 15, 162 Bq kg^{-1},respectively. Results suggest that both experimental and theoretical K-40 values are compatible. Further, obtained results are compared to average K-40 concentration in soils within the US. Lastly, radioactivity based radiological health hazard indicating parameters are computed. Results indicated that K-40 concentration in potassium enhanced fertilizers considered in this study is significantly higher to the average K-40 concentration in US soils and computed health hazard indicating parameters are significantly higher than world-wide averages.

Introduction/Background

Fertilizers play a major role in improvement of plants growth and enhancement of crop yields. One of the essential elements, potassium, helps in root growth and drought resistance of plants. Potash fertilizers are derived from potash rocks cored from earth's crust and consist of trace quantities of Naturally Occurring Radioactive Materials (NORM). With an intent of increasing concentration of potassium, manufacturers increase percentage of potash, and this results in enhancement of radioactive concentrations (specifically K-40) in fertilizers.

The state of Mississippi is one of the agriculture-based states in the U.S. and ~20% of its workforce are directly or indirectly involved with farming industry and may be handling fertilizers as part of their job. It is vital that fertilizers are evaluated for radioactivity levels as potassium enriched fertilizers may contain elevated levels of NORM and can pose health hazards to farm workers.

Risk/Concerns:

- US EPA acknowledged presence of fertilizer nutrient deposits in water bodies/ creeks/ soils.
- At least 20% of Mississippi population are directly/indirectly involved with farming industry.
- No stringent regulations are in place as fertilizers consists of radioactive materials that are naturally occurring.
- As radiation dose is directly proportional to amount of radioactivity, enhanced NORM/rock in fertilizers may result in significant dose to farmers/worker when handling fertilizers.

Procedure

Theoretical Estimation:

Fraction of K in K_2O = 0.83

Percent of K in fertilizer (0-0-60) = 0.83 x 0.6 =0.498

Mass of K in one bag (50lb or 22.68 kg) = 0.498x 22.68kg = 11.294kg

Natural abundance of K-40 in K is 0.0117%

Mass of K-40 in one bag = 1.32 x10^{-3} kg = 1.32 g

Number of K-40 atoms (N) = Avogadro Number x $\left(\frac{1}{molar\ mass}\right)$x1.32g

$= (6.023 \times 10^{23}\ \frac{atoms}{mole}) \times (\frac{1}{40g/mole})$x1.32g

$= 1.5 \times 10^{22}\ \frac{atoms}{g} = 1.5 \times 10^{25}\ \frac{atoms}{kg}$

Half-life ($T_{1/2}$) of K-40= 4.04 x 10^{16} s and Decay constant (λ) = $\frac{0.693}{T1/2}$

K-40 activity in 22.68kg /1 bag = λ N = 3.5 x10^{5} Bq

K-40 activity per kg of fertilizer = 1.5 x10^{4} Bq kg^{-1}

Experimental Measurement:

- Fifteen bags of 0-0-60 fertilizer were collected from a local market. 1- 2 kg of fertilizer was scooped from each bag and was transferred to individual aluminum pans and then dried at 110^{0} C for 24 hours.
- Each sample was then transferred into a 0.5 L Marinelli beaker, weighed, and hermetically sealed with parafilm.
- The radioactivity measurement of fertilizer samples was conducted using a High Purity Germanium detector (HPGe).
- Each sample was analyzed for 24 hours.
- K-40 was measured by identifying its gamma energy of 1460.8 keV.
- Background radiation is measured by placing empty Marinelli beaker on the detector and analyzed for 24 hours.
- Genie-2000 software subtracts background radioactivity from the fertilizer sample's radioactivity and provides net radioactivity in the sample.

Calculation of Absorbed Dose (D): The outdoor absorbed gamma dose rate in the air at 1 m height from the ground for the samples was estimated in nGyh^{-1} using the equation below (UNSCEAR, 2008):

$$D(nGyh^{-1}) = 0.0417SA_{K} + 0.462\ SA_{Ra} + 0.604\ SA_{Th}$$

Where D is the absorbed dose in nGy h^{-1}; SA_K,S A_{Ra}, and SA_{Th} are the specific activities of K-40, Ra-226, and Th-232 in (Bq kg^{-1}), respectively, in the fertilizers. To comply with the safety standards, the estimated dose values should be less than 59 nGy y^{-1} (UNSCEAR, 2000)

Calculation of Annual Effective Dose Rate (AEDR): The annual effective dose rate due to external exposure was estimated from outdoor absorbed gamma dose rate considering the conversion factor for adults (0.7 x 10^{-3} Sv Gy^{-1}). Individuals spend 80% of the time indoors and 20% of the time outdoors. The annual effective dose rate was estimated in μSvy^{-1} by using the following formula (UNSCEAR, 2008).

$$AEDR(\mu Svy^{-1}) = D \times (0.7 \times 10^{-3}) \times (8766 \times 0.2)$$

World-wide average of AEDR in soils reported by UNSCEAR, 2008 is 70 μSvy^{-1}

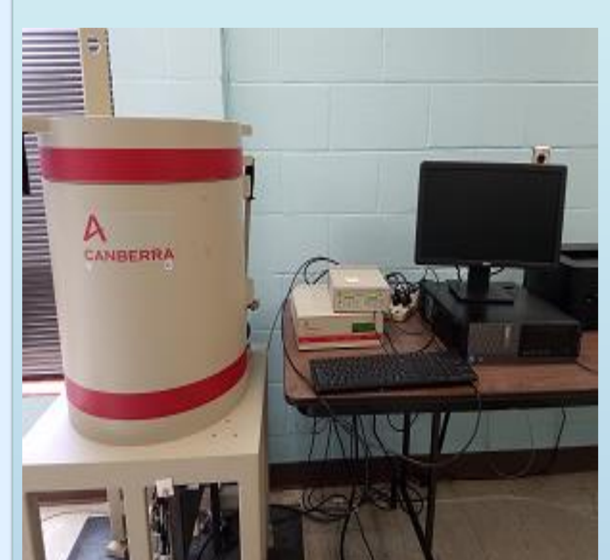

Figure 1: Germanium detector assembly

Figure 2: Sample analysis

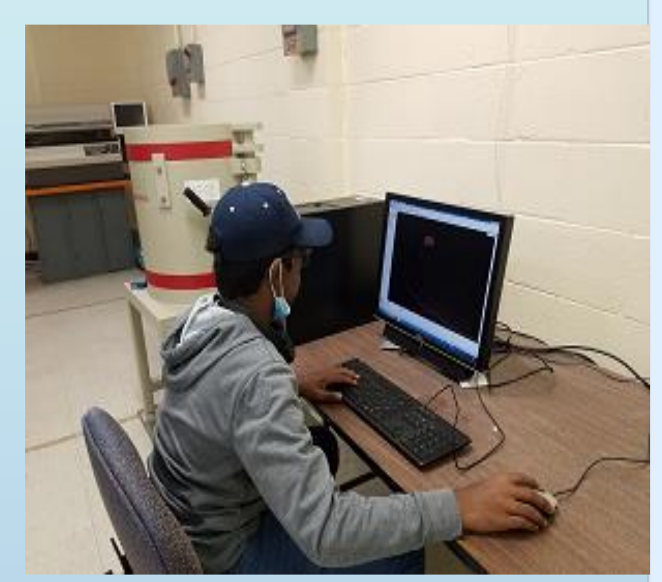

Figure 3: Data analyses

Results

A radioactivity-based study was performed on selected fertilizers (0-0-60). Experiment was divided into two categories- theoretical estimation and experimental measurement of K-40 in 0-0-60 fertilizers. Results from this study are provided in Table 1. As Potash rocks are mined from soils, they consisted of trace quantities of Ra-226 and Th0232 along with enriched Potassium(K-40). The theoretical K-40 indicated an activity of 1.5 x10^{4} Bq kg^{-1} while the experimental value was . Comparison of experimental and theoretical radioactivity values in fertilizers considered in this study are provided in Figure 3.

Table 1: Activities of Key Isotopes in 0-0-60 Fertilizers

Results	Ra-226 (Bq kg^{-1})	Th-232 (Bq kg^{-1})	K-40 (Bq kg^{-1})
Theoretical	NA	NA	15,110± 122
Experimental	1.1 ± 0.13	0.43 ± 0.08	15,162± 124

Discussion

- Experimental K-40 activity measured 15,162 Bq kg^{-1}.
- Theoretical K-40 activity calculated 15,110 Bq kg^{-1}.
- As Potash rock is mined from the earth's crust, it still contained trace quantities of Ra-226 and Th-232 (other NORM isotopes present in soils).
- Percent error between expected (computational) and experimental K-40 radioactivity values is less than 1%.
- Word-wide average K-40 in soils is 481 Bq kg $^{-1}$, while K-40 in 0-0-60 fertilizers was 15,162 Bq kg^{-1}.
- A comparison of measured K-40 activity in 0-0-60 fertilizer to world-wide average K-40 in soils is provided in Figure 5.

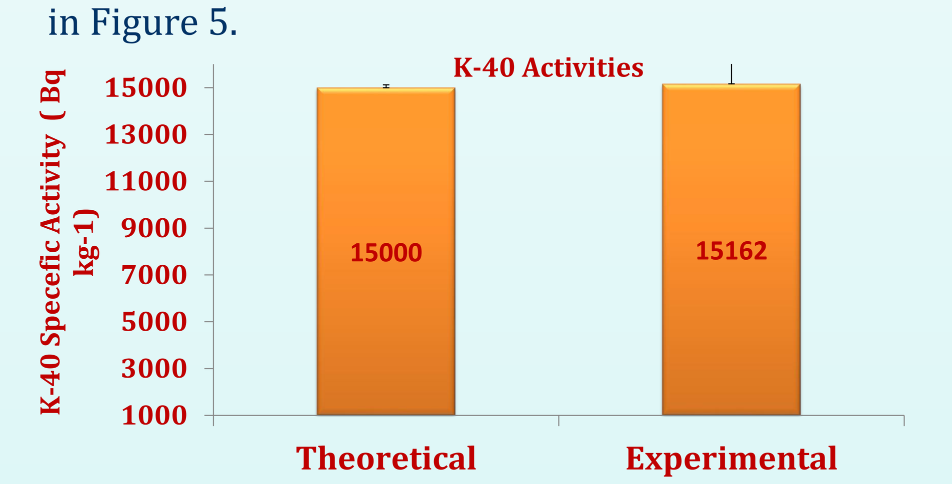

Figure 4: Comparison of experimental and world-wide average in soils

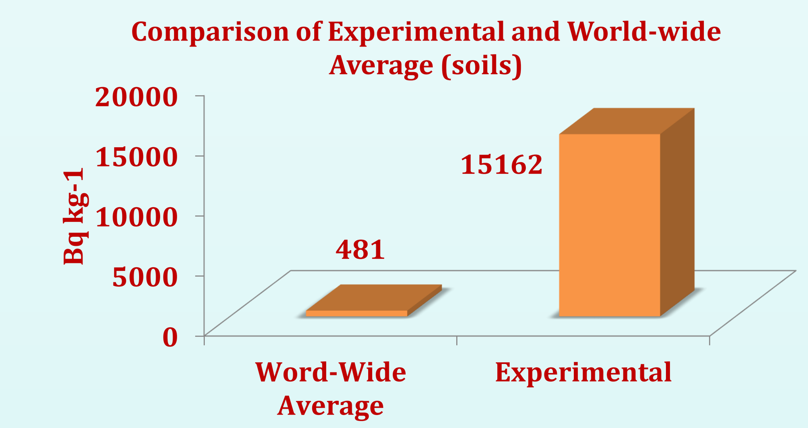

Figure 5: Comparison of experimental and calculated K-40

- Comparative results suggest that the K-40 activity in fertilizers considered in this study is ~ 32 times to the average K-40 in soils.
- Higher K-40 resulted due to enhancement of Potash rock.
- Calculated activity based Annual Effective Dose and Absorbed Dose values are significantly higher than the world-wide averages.
- Table 2 and Figures 6 & 7 provides graphical comparison of calculated radiological health hazard parameters with world-wide average values.

Table 2: Calculated Radiological Health Hazard Indicating Parameters and their World-wide Averages

	Acceptable Limit/World-wide Average	Experimental Values
Annual Effective Dose Rate (AEDR)	70 μSvy^{-1}	776 μSvy^{-1}
Absorbed Gamma Dose Rate (External)	59 nGy y^{-1}	633 nGy y^{-1}

Conclusions

- Fertilizers are prominent in farming industries as they help to increase plants growth and crop yields.
- Fertilizers are manufactured from rocks derived from the soil/earth.
- Rocks contain trace quantities of Naturally Occurring Radioactive Materials (NORM).
- Increasing concentration of any element (Potassium/Phosphorous) will result in higher radioactivity.
- A computational method and experimental method (gamma spectrometry) was conducted to measure K-40 in 0-0-60 fertilizer.
- As hypothesized, experimental and computational methods indicated similar radioactivity concentrations for K-40.
- As concentration of Potash rock was significantly increased, it resulted in higher K-40 radioactivity.
- K-40 in 0-0-60 fertilizers is almost 32 times of the average K-40 in soils.
- Computed radiological health hazard parameters of Annual Effective Dose Rate (AEDR) and Absorbed Gamma Dose Rate are significantly higher than their world-wide average values (~10 times)
- From this study, it could be concluded that regulators must develop stringent regulations to workers when handling these NORM enhanced materials (fertilizers).

References

- 1.Billa, J., Han, F., Didla, S., Ankrah, M., Yu, H., Dimpah, J., Adzanu, S. (2015). Evaluation of Radioactivity Levels in Fertilizers Commonly Used in the Southern USA. *Journal of Radioanalytical and Nuclear Chemistry*, 183-191
- UNSCEAR 2000 Radiation Sources and effects of ionizing radiation New York: United Nations Scientific Committee on the Effect of Atomic Radiation.
- UNSCEAR 2008 Radiation Sources and effects of ionizing radiation New York: United Nations Scientific Committee on the Effect of Atomic Radiation.