

# Non-destructive determination of $^{40}\text{K}$ in Marijuana and the effective radiation dose to the body

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**Abstract**— Total potassium (0.84 % to 3.15%; mean of 1.93 %) in marijuana buds was determined from the  $^{41}\text{K} (n,\gamma) ^{42}\text{K}$  capture reaction by instrumental neutron activation analysis. The mass fraction of  $^{40}\text{K}$  was derived using the natural isotopic ratios and the activity equation  $A=\lambda N$  used to calculate the activity concentration of  $^{40}\text{K}$  (253 to 946 Bq kg $^{-1}$ , mean of 581 Bq kg $^{-1}$ ). Simulated smoking experiments show that over 90% of  $^{40}\text{K}$  is retained in the cigarette ash. Accepted methods of determining effective dose to the body from  $^{40}\text{K}$  inhalation are likely overestimations for both marijuana and tobacco cigarette smoke.

**Index Terms**— Potassium-40, Neutron Activation Analysis, Radiation Dose, Marijuana, Jamaica

## I. INTRODUCTION

The primordial radionuclide  $^{40}\text{K}$  makes up 0.0117% of total potassium and is taken up through ingestion and to a lesser extent inhalation in the same manner as the two non-radioactive isotopes of potassium  $^{39}\text{K}$  (93.26%) and  $^{41}\text{K}$  (6.73%). The dose received from  $^{40}\text{K}$  because of the ionizing radiation associated with its radioactive decay makes this radionuclide an internal hazard [1].

$^{40}\text{K}$  is typically determined directly by passive gamma spectroscopy of the 1460.8 keV photon. To determine this radionuclide accurately by this technique one requires large masses and measurement periods of several hours per sample. In the case of the cannabis samples which are the result of samples seized by law enforcement agencies and where the amount of sample is important for forensic and evidential purposes, mass comes at a premium. For these reasons the indirect determination of the activity of  $^{40}\text{K}$  from total potassium by instrumental neutron activation analysis (INAA) was an appropriate alternative. Total potassium by neutron activation analysis (NAA) is determined via the  $^{41}\text{K} (n,\gamma) ^{42}\text{K}$  capture reaction. Because the percentage of  $^{40}\text{K}$  is always 0.0117% of total potassium the mass fraction of  $^{40}\text{K}$  in the sample can be determined using the natural isotopic ratios [1] and employing the activity equation  $A=\lambda N$  to determine the activity of  $^{40}\text{K}$  [2].

Several studies have evaluated the radioactivity of tobacco leaves and the effective dose induced to smokers from naturally occurring radionuclides including  $^{40}\text{K}$  [3-5]. Cannabis (both plant and resin) is the most widely produced, consumed, and trafficked illicit drug in the world and had an estimated 183 million users in 2014 [6-7]. With the significant

number of users, the aim of this study was to indirectly determine the activity of  $^{40}\text{K}$  in marijuana from Jamaica using INAA as a method of rapid analysis and to determine the effective dose to the smoker.

## II. MATERIALS AND METHODS

### A. Sample Preparation

Samples of marijuana (*Cannabis sativa* L.) were collected following seizure by local law enforcement. Following chain of custody procedures, the samples were transported to, and stored at the irradiation facilities where sample preparation, irradiation and analysis took place. The buds of each plant were cut from the stems. Buds were then weighed in an aluminium foil weighing boat, washed in tap water and again in de-ionized water. The samples were oven-dried at 60°C for two days, cooled in a desiccator for 20 minutes and then weighed before being ground to a fine powder using a Fritsch Pulverisette 2 automated agate mortar and pestle (Fritsch, Germany).

### B. Sample Irradiation and Analysis

Samples were irradiated using the SLOWPOKE-2 research reactor (Atomic Energy of Canada Limited, ON, Canada).  $^{42}\text{K}$  has a half-life of 12.4 hours making it suitable for determination by two irradiation regimes. Approximately 500 mg of bud sample was weighed out in 1.65 cm $^3$  pre-cleaned polyethylene capsules or pre-cleaned double polyethylene bags and heat sealed in pre-cleaned 9.50 cm $^3$  polyethylene vials. Samples were irradiated for 4 hours at a thermal neutron flux of  $\Phi_{\text{th}} = 1 \times 10^{12} \text{ n cm}^{-2} \text{ s}^{-1}$ , allowed a decay period of 4 days and counted for up to 3600 seconds and for 3 minutes at a thermal neutron flux of  $\Phi_{\text{th}} = 5 \times 10^{11} \text{ n cm}^{-2} \text{ s}^{-1}$  and allowed decay periods of approximately 60 minutes before counting for 600 seconds [8]. The total potassium results showed agreement of better than 95% between the two irradiation regimes. The samples were counted on an Ortec High-Purity germanium (HPGe) coaxial gamma photon detector system with an efficiency of 71% and a resolution of 1.9 keV at the  $^{60}\text{Co}$  1332 keV gamma line and a Peak to Compton ratio of 78:1 at the  $^{60}\text{Co}$  1332 keV gamma line.

### C. Quality Control

The irradiation regime and counting geometries for elements are standardized by irradiation of single element standards. The sensitivity constants are recorded in tables that are used for extended periods and without the need for the co-irradiation of flux monitors or standards [9]. Certified reference materials used for this study were the IAEA (International Atomic Energy Agency, Vienna, Austria) 336 – Lichens, NIST (National Institute of Standards and Technology, MD, USA) 1547 Peach Leaves and NIST 1515 Apple Leaves. These reference materials were analysed under the irradiation and analytical conditions previously stated as part of sample batches. Observed results were within the 95% confidence limits in the certificate for each reference material.

### III. RESULTS AND DISCUSSION

The total potassium in the marijuana buds ranged from 0.84 % to 3.15% with a mean mass fraction of 1.93% (see Table 1). The activity concentrations of  $^{40}\text{K}$  in the samples of marijuana ranged from 253 to 946 Bq kg<sup>-1</sup> with a mean activity of 581 Bq kg<sup>-1</sup> (see Table I). Considering the lack of papers on radioactivity of marijuana buds, comparison with tobacco leaves may be most appropriate considering that both are used as ingredients for cigarettes. In the work looking at the radioactivity of tobacco leaves from Greece, the  $^{40}\text{K}$  activity concentration ranged from 273 to 2080 Bq kg<sup>-1</sup> with a mean of 823 Bq kg<sup>-1</sup> [4]. The  $^{40}\text{K}$  activity concentrations from Mexican brands of tobacco ranged from 1020 to 1590 Bq kg<sup>-1</sup> with a mean of approximately 1290 Bq kg<sup>-1</sup> [3]. In a Jamaican study the minor and trace element content of various tobacco leaf samples were analysed for by INAA [10]. The same methodology used in this paper could be used to derive the  $^{40}\text{K}$  activities; the artisanal tobacco  $^{40}\text{K}$  activities ranged from 871 to 1742 Bq kg<sup>-1</sup> with a mean activity of 1231 Bq kg<sup>-1</sup>. The two local brands assessed had  $^{40}\text{K}$  activities of 721 and 781 Bq kg<sup>-1</sup> and the imported brands ranged from 751 to 1502 Bq kg<sup>-1</sup> with a mean activity of 1051 Bq kg<sup>-1</sup> [10]. The potassium content and therefore the  $^{40}\text{K}$  activities appear to be lower in marijuana buds than in tobacco leaves. This may be a result species-specific uptake, the use of marginal lands and fertilizer use (or lack thereof) for the illicit crop or a combination of these factors.

Given the large population of cannabis users, globally it is useful to determine the dose received from exposure to  $^{40}\text{K}$  activity from inhalation. The industrialized nature of tobacco cigarette production means that the tobacco found in each cigarette is standardized. The typical number of cigarettes in a pack is twenty and the consumption of tobacco by a smoker can be determined by how many packs per day or other unit time are consumed. There, however is very little consensus on the given mass of cannabis to be found in a marijuana cigarette. In the UNODC's Bulletin on Narcotics: Review of the World Cannabis Situation [11], the cannabis content of a typical cigarette ranged from as low as 0.1 grams in the Netherlands to as high as 3 grams in Jamaica. A study on daily

marijuana smokers in Jamaica estimated an average consumption of approximately 18 grams of cannabis per day [12]. In a 2013 report for the Washington State Liquor Control Board a heavy user of marijuana was defined as one who consumed cannabis for 21 or more days per month and estimated a consumption for this user as 1.6 grams per day of cannabis and a regular user as 0.67 grams of cannabis consumed per day [13].

**Table I** Total Potassium,  $^{40}\text{K}$  mass fraction and  $^{40}\text{K}$  activity in Marijuana Buds

Sample ID	Total K (%)	$^{40}\text{K}$ ( $\mu\text{g g}^{-1}$ )	$^{40}\text{K}$ Activity (Bq kg <sup>-1</sup> )
BAGDALE MT. #1 – ICE BUDS	1.03	1.21	310
BAGDALE MT. #2 – MIX BUDS	1.52	1.78	457
BAGDALE MT. #5 – MIX BUDS	0.98	1.14	293
BAGDALE MT. #13 – PS BUDS	1.56	1.82	467
BAGDALE MT. #3 – PS – BUDS	1.11	1.30	333
BAGDALE MT. #9 – ICE BUDS	0.91	1.06	273
MT. AIRY A PS MIX #4 BUDS	1.04	1.22	312
BAGDALE MT. #8 – MIX BUDS	1.22	1.43	367
ST. ELIZ #10 ORIGINAL PS BUDS	0.84	0.99	253
MT. AIRY #1 PSM BUDS	2.21	2.58	663
#1 MANGO HILL MIX BUDS	1.09	1.27	326
RIVER VIEW SAMPLE 1	2.58	3.01	774
RIVER VIEW SAMPLE 2	2.81	3.29	844
RIVER VIEW SAMPLE 3	2.51	2.93	753
RIVER VIEW SAMPLE 4	2.57	3.00	771
SOUTH CAMP ROAD BUD	2.86	3.35	860
AUGUST TOWN BUD	2.70	3.16	811
C. LANE BUDS	3.15	3.69	946
WEED ORIGINAL	2.86	3.35	859
WEED A	2.95	3.45	886
RED JAM + WOW BUDS	2.11	2.47	633

### A. Effective Dose Estimate

Using the numbers by Kilmer et al [13] as an estimate of a heavy and regular user, 1.6 and 0.67 grams per day of cannabis consumed respectively, and assuming this mass is cannabis herb that is smoked exclusively then the annual consumption of marijuana would be 0.584 kg y<sup>-1</sup> (heavy user) and 0.245 kg y<sup>-1</sup> (regular user). Table I shows the range of <sup>40</sup>K activities for the samples analysed from 253 to 946 Bq kg<sup>-1</sup> with a mean activity of 581 Bq kg<sup>-1</sup>. The annual effective dose H<sub>E</sub> (Sv y<sup>-1</sup>) due to the inhalation of <sup>40</sup>K for adults is given by Eq. (1):

$$H_E = 0.75 \times M_T \times C_i \times F \quad (1)$$

Where M<sub>T</sub> is the annual mass of cannabis consumed by the heavy or regular user, C<sub>i</sub> (Bq kg<sup>-1</sup>) is the activity concentration of the radionuclide in question, in this case <sup>40</sup>K and F is the effective dose coefficient for the radionuclide in Sv Bq<sup>-1</sup>. The effective dose coefficient for <sup>40</sup>K for adults (described as aged 16 – 70 yrs) is 2.1 x 10<sup>-9</sup> [14-15]. The 0.75 in Eq. (1) is the fraction of the radioisotope that is liberated from the tobacco and is therefore available for inhalation from the cigarette smoke. This coefficient is based on studies showing that, on average, 25% of total polonium found in the tobacco was retained in the filter and ash of tobacco cigarettes while the remaining 75% of total polonium content was found in cigarette smoke. This fraction of polonium is then available for inhalation and deposition in the lungs [16-17]. An important assumption is that <sup>40</sup>K is volatilized to an extent that makes approximately 75% of the radionuclide available from the marijuana cigarette smoke. A simulated smoking exercise was conducted to test this assumption. The source cannabis sample was analysed by INAA and found to contain a mean mass fraction of 2.78% total potassium. The rolling paper (Rizla™) was weighed and analysed and found to have a mean total potassium mass fraction of 570 µg g<sup>-1</sup>. This corresponded to an absolute mass of total potassium of approximately 57 µg. Similar masses of cannabis sample were weighed out (approximately 1.98 g) for preparation of the cigarettes which corresponded to an absolute mass of total potassium of 0.0549 g. Marijuana cigarettes were handmade using the mass and rolling paper. The potassium content of the rolling paper is approximately 0.1 percent of the potassium in the cannabis sample and its contribution can be considered insignificant. The mass of the unsmoked portion of the cigarette was subtracted from the initial weight of the marijuana cigarette and the absolute mass of the potassium of the smoked cigarette estimated using the average content of the cannabis as analysed (2.78%). The ash was carefully collected, weighed and analysed by INAA. The mass fraction of potassium in the ash ranged from 18.6 to 19.7 %.

**Table II** Percentage Potassium retained in Marijuana Cigarette Ash

	<b>Absolute Mass of K (g)-cigarette</b>	<b>Absolute Mass of K (g)-ash</b>	<b>% of K in ash</b>
Cigarette A	0.046	0.046	98.4
Cigarette B	0.051	0.047	91.3
Cigarette C	0.053	0.052	98.1

The results, displayed in Table II, show that the percentage potassium retained in the ash ranged from 91.3 to 98.4 %. If one considers the most conservative estimate, only approximately 9% of the potassium and therefore the <sup>40</sup>K is available for inhalation and deposition in the lungs. These results reflect findings published by V.C Runeckles, which indicated that 90% of <sup>40</sup>K was retained in the ash of tobacco cigarettes [18] and in unpublished data subsequently generated by ICENS during analysis for the published tobacco study [10].

Based on Eq. (1), Table 3 shows that for the heavy smoker the annual effective dose ranges from 0.23 to 0.87 µSv yr<sup>-1</sup> with a mean annual effective dose of 0.53 µSv yr<sup>-1</sup> while the regular user would range from 0.10 to 0.36 µSv yr<sup>-1</sup> with a mean of 0.22 µSv yr<sup>-1</sup>. However, based on the <sup>40</sup>K found in the ash, more accurate annual effective doses would range from 0.028 to 0.104 µSv yr<sup>-1</sup> with a mean of 0.064 µSv yr<sup>-1</sup> for the heavy smoker and 0.012 to 0.044 µSv yr<sup>-1</sup> with a mean of 0.027 µSv yr<sup>-1</sup> for the regular smoker. These results are also displayed in Table III. Even if one considers the numbers for the Jamaican marijuana user data implausibly high or flawed [19], the hazard presented would be minor.

**Table III** Annual Effective Dose for Smokers consuming 1.6 and 0.67 g d<sup>-1</sup> Cannabis [13]

Sample ID	A (Bq kg <sup>-1</sup> )	H <sub>E</sub> Heavy (μSv yr <sup>-1</sup> )	H <sub>E</sub> Regular (μSv yr <sup>-1</sup> )	Corrected H <sub>E</sub> Heavy (μSv yr <sup>-1</sup> )	Corrected H <sub>E</sub> Regular (μSv yr <sup>-1</sup> )
BAGDALE MT. #1 - ICE BUDS	310	0.29	0.12	0.034	0.014
BAGDALE MT. #2 - MIX BUDS	457	0.42	0.18	0.050	0.021
BAGDALE MT. #5 - MIX BUDS	293	0.27	0.11	0.032	0.014
BAGDALE MT. #13 - PS BUDS	467	0.43	0.18	0.052	0.022
BAGDALE MT. #3 - PS - BUDS	333	0.31	0.13	0.037	0.015
BAGDALE MT. #9 - ICE BUDS	273	0.25	0.11	0.030	0.013
MT. AIRY A PS MIX #4 BUDS	312	0.29	0.12	0.034	0.014
BAGDALE MT. #8 - MIX BUDS	367	0.34	0.14	0.041	0.017
ST. ELIZ #10 ORIGINAL PS BUDS	253	0.23	0.10	0.028	0.012
MT. AIRY #1 PSM BUDS	663	0.61	0.26	0.073	0.031
#1 MANGO HILL MIX BUDS	326	0.30	0.13	0.036	0.015
RIVER VIEW SAMPLE 1	774	0.71	0.30	0.085	0.036
RIVER VIEW SAMPLE 2	844	0.78	0.33	0.093	0.039
RIVER VIEW SAMPLE 3	753	0.69	0.29	0.083	0.035
RIVER VIEW SAMPLE 4	771	0.71	0.30	0.085	0.036
SOUTH CAMP ROAD BUD	860	0.79	0.33	0.095	0.040
AUGUST TOWN BUD	811	0.75	0.31	0.090	0.037
C. LANE BUDS	946	0.87	0.36	0.104	0.044
WEED ORIGINAL	859	0.79	0.33	0.095	0.040
WEED A	886	0.81	0.34	0.098	0.041
RED JAM + WOW BUDS	633	0.58	0.24	0.070	0.029

#### IV. CONCLUSIONS

<sup>40</sup>K is classified as a Type F material, meaning it is readily absorbed into the blood stream from the respiratory tract [15]. Though ingestion from foods is the more common route of dose exposure the lifetime cancer mortality risk coefficient is higher from inhalation at  $7.8 \times 10^{-12} \text{ Bq}^{-1}$  vs  $8.1 \times 10^{-13} \text{ Bq}^{-1}$  for ingestion [1]. At approximately 0.8 g per tobacco cigarette the consumption of tobacco per year may be up to 9kg [3-4]. This exceeds the levels of the Jamaican marijuana smoker postulated at 6.6 kg. Using the statistics for Jamaican tobacco and suggesting that approximately 9% of the potassium is available for inhalation that would equal an estimated annual effective dose of about  $2.09 \mu\text{Sv yr}^{-1}$  from <sup>40</sup>K exposure. This would be significantly higher than the credible dose from marijuana simply because of the mass of cannabis consumed versus tobacco and would still be quite low. Historical studies [20-21] suggest that <sup>40</sup>K would not be volatilized significantly at tobacco cigarette burning temperatures and therefore not be a source of significant dose to the smoker. It appears that the same holds true for <sup>40</sup>K in the marijuana cigarette.

Using INAA to determine total potassium is an accurate, rapid and chemically non-destructive method of calculating <sup>40</sup>K activity concentrations. Potassium and by extension the <sup>40</sup>K found in the marijuana is via root uptake from soils and possibly fertilizers. Because of the relatively large uncertainty in consumption data the exposure of a smoker of marijuana to <sup>40</sup>K activity could be grossly over or underestimated. Traditional calculations use 75% as the amount of radionuclide available for inhalation. This work and others suggest that the amount is closer to 9 or 10%; the effective dose to the body is therefore significantly lower. Estimated marijuana consumption levels indicate that <sup>40</sup>K exposure will be significantly lower from marijuana than from tobacco cigarettes.

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