Essays on Nuclear Energy & Radioactive Waste Management

Ricardo Bastos Smith
(Org.)

Authors:
Ana Paula Gimenes Tessaro
Bianca Geraldo
Daiane Cristini Barbosa de Souza
Fernanda Romero
Indranil Bisuri
Júlio Takehiro Marumo
Luan Teixeira Vieira Cheberle
Mahima Sachdeva
Mychelle Munyck Linhares Rosa
Natalie Costa Rolindo
Ricardo Bastos Smith
Roberto Vicente
Tereza Cristina Salvetti

ipen

GÊNIO CRIADOR

Essays on Nuclear Energy & Radioactive Waste Management

Ricardo Bastos Smith (Org.)

Authors:
Ana Paula Gimenes Tessaro
Bianca Geraldo
Daiane Cristini Barbosa de Souza
Fernanda Romero
Indranil Bisuri
Júlio Takehiro Marumo
Luan Teixeira Vieira Cheberle
Mahima Sachdeva
Mychelle Munyck Linhares Rosa
Natalie Costa Rolindo
Ricardo Bastos Smith
Roberto Vicente
Tereza Cristina Salvetti

ipen
GÊNIO CRIADOR

Editorial lead:
Cleusa Kazue Sakamoto

Editorial project:
Gênio Criador Editora

Text revision & book cover:
Ricardo Bastos Smith

Cataloging in Publication (CIP) International Data
Angélica Ilacqua CRB-8/7057

Essays on nuclear energy & radioactive waste management [livro eletrônico] / Ana Paula Gimenes Tessaro...[et al] ; organizado por Ricardo Bastos Smith. -- São Paulo : Gênio Criador, 2021.
171 p.

Bibliografia
ISBN 978-65-86142-41-9 (e-book)

1. Tecnologia nuclear 2. Usinas nucleares 3. Resíduos radiativos, Eliminação dos I. Smith, Ricardo Bastos

21-2681 CDD 333.792 4

1st. edition, 2021

Av. Brigadeiro Faria Lima, 1616 - sala 804
Jardim Paulistano, São Paulo - SP, 01451-001
http://geniocriador.com.br

- 8 -
Determination of Potassium-40 in some Beer Styles[11]

Ricardo B. Smith
Roberto Vicente
Nuclear and Energy Research Institute - IPEN-CNEN/SP, Brazil
Luan T. V. Cheberle
Mychelle M.L. Rosa
Ambientis Radioprotection

Abstract: The radiation from radioactive isotopes of the natural radioactive series of thorium (Th-232) and uranium (U-238 and U-235), as well as radioactive potassium (K-40), are the major contributors of natural terrestrial radiation. The K-40 is a radionuclide that occurs naturally in a fixed ratio with the stable potassium. Potassium is an essential element for humans and its concentration in the body is controlled by metabolic processes. Beer is a highly widespread drink and is consumed worldwide. One of the great characteristics of the variety of beers, in their styles, is the possibility of using innumerable ingredients in their production, such as different fruits, seasonings, leaves and roots, grains, malts and hops, and the choice of ingredients can interfere directly in their properties. The present study presents the K-40 determination in beers with different styles applying the technique of analysis by gamma spectrometry. Reference material IAEA-327-Soil was analyzed for validation of the methodology. The results differ mainly due to the different raw materials used in the beer production.

Resumo: A radiação de isótopos radioativos das séries radioativas naturais do tório (Th-232) e do urânio (U-238 e U-235), bem como o potássio radioativo (K-40), são os principais contribuintes para a radiação terrestre natural. O K-40 é um radionuclídeo que ocorre naturalmente em uma proporção fixa com o potássio estável. O potássio é um elemento essencial para o ser humano, e sua

11 Poster presented at the 2019 International Nuclear Atlantic Conference (INAC) on October 21-25, 2019 in the city of Santos, SP., Brazil. Available at: <https://inis.iaea.org/search/search.aspx?orig_q=RN:51010417>.

concentração no corpo é controlada por processos metabólicos. A cerveja é uma bebida muito difundida e consumida em todo o mundo. Uma das grandes características da variedade de cervejas, em seus estilos, é a possibilidade de se utilizar inúmeros ingredientes em sua produção, como frutas diversas, temperos, folhas e raízes, grãos, maltes e lúpulo, e a escolha dos ingredientes pode interferir diretamente em suas propriedades. O presente estudo apresenta a determinação do K-40 em cervejas de diferentes estilos aplicando a técnica de análise por espectrometria gama. O material de referência IAEA-327-Solo foi analisado para validação da metodologia. Os resultados diferem principalmente devido às diferentes matérias-primas utilizadas na produção de cerveja.

Introduction

Radioactive isotopes (radionuclides) are naturally present in the environment and in all kinds of matter. Radiation originates from radioactive materials found in soil, water and air, and can be detected in food and beverages such as beer, with the concentration of natural radionuclides varying according to several factors, such as local geology, climate and agricultural practices [1].

The radiation from radioactive isotopes of the natural radioactive series of thorium (^{232}Th) and uranium (^{235}U and ^{238}U), as well as the radioisotope of potassium (^{40}K), are the major contributors of natural terrestrial radiation [2]. Potassium-40 (^{40}K) is a radioactive isotope of potassium which has a half-life of 1.251×10^9 years. In approximately 89.28% of the decays, it turns into Calcium-40, and in 10.72% it decays to Argon-40 [3].

One of the great characteristics of the enormous variety of beers, in their styles, is the possibility of using the most different ingredients in their production: hops, malts, fruits and condiments, leaves and roots, grains, sky is the limit in the choice of ingredients, and it is up to the brewer to tailor the proportions and combinations in order to create a unique and pleasurable taste. But what would be your reaction if you read

it, on a beer label, that it contains radiation? “Lo, how did such thing get here on the shelf?”

Technically speaking, every food is slightly radioactive. That is because every food and any other organic compounds contain carbon, which naturally exists in a mixture of its isotopes, including Carbon-14, which is radioactive. The calculation of the $^{14}C/^{12}C$ ratio is used for Carbon-14 dating, a method for identifying the age of fossils [4].

In the United States, the measurement of radioactivity in alcoholic beverages is even one of the best methods for quality control of the origin of alcohol in alcoholic beverages: in fact, non-radioactive alcoholic beverages in the United States are illegal; they should present at least 400 disintegrations per minute (DPM) for every 750 mL [5]. That is because the US government established that alcohol for consumption must originate from vegetables, such as grapes, grains or fruits. This way, the alcohol produced from petroleum is left out. Regardless of the reasons, since petroleum alcohol is chemically identical to natural alcohol, as safe as (or unsafe, depending on the point of view) and with exactly the same taste, how then to identify the difference between the two types of alcohol?

There is only one reliable test: to measure its radioactivity. The carbon of natural alcohol is originated from plants. Plants absorb carbon from the atmosphere through carbon dioxide. Carbon dioxide from the atmosphere is radioactive, due to the continuous bombardment of cosmic rays - particles that come from space and collide with the nitrogen atoms, forming carbon-14, which is radioactive. Only one atom in a trillion carbon atoms in the atmosphere is radioactive, but that is sufficient to be detectable.

The petroleum carbon also came from the atmosphere, but it was buried tens of millions of years ago, being isolated from atmospheric radioactivity. The radioactive carbon has a half-life of about 5,700 years, and after a hundred million years,

it is almost impossible to have even one carbon-14 atom left. Of course, counterfeiters could get carbon-14 somehow and inject into their drinks, but that is beyond the capacity of the vast majority of them [5].

And it is not only of ^{14}C that there are radioactive isotopes in food: in minimum proportions, a good part of the Periodic Table is also within our favorite dishes. An element that stands out is potassium, which is essential for the human being and which concentration in the body is controlled by the metabolism. Potassium-40, its radioactive isotope, is found in various vegetables and fruits, especially in bananas, papayas, beets, sweet potatoes, oats, almonds, among others.

There is even an informal measurement for comparison of the radiation between different kinds of food, and even between practically any dose rates: the Banana Equivalent Dose (BED), which is much simpler to understand than the usual radiation units of measure (becquerels, sieverts, grays or rems). After all, is there anything more obvious than a banana? [6].

A BED is equivalent to 0.1 microsievert in a radiation dose [7]. Damn, should I eat fewer bananas then? Actually, the difference between a medicine and a poison is in its dose: for you to absorb a high radiation dose from bananas, close to being lethal, you should have to eat something around 40,000,000 bananas. Do not try this at home.

Anyway, beer surely tends to be far more attractive to be consumed, in quantity, than bananas; however, unlike these, because of the alcohol in it you will surely be asleep well before the first hundred thousand.

Even water can be radioactive, containing tritium atoms (the radioactive isotope of hydrogen, with two more neutrons). Part of such water comes with the rains, which bring the tritium produced by the cosmic rays in the upper part of the atmosphere; another part is produced by nuclear reactors on the planet [8]. In case you suspect you drank too much of this

water, do not worry: grab a beer! Its diuretic properties will readily remove the excess tritium from your body [9].

The ethanol alcohol is a scavenger of free radicals caused by radiation, and therefore it is considered a radioprotector. However, this is of academic interest only and not suitable for clinical applications, because of its toxicity at radioprotective concentrations [10], [11]. Monobe and Ando [12] have shown that beer intake reduces chromosomal aberrations induced by radiation. However, another study found that the radioprotective effects of beer are not due to the alcohol contained in it, but to other ingredients [13].

Actually, for millennia beer has been produced with beneficial effects for humans, especially after the introduction of hops in its manufacture, around the 12th and 13th centuries [14]. Later in the 21st century, further studies have reported several beneficial characteristics of this beverage: in Germany, Scherr and others concluded that beer without alcohol has anti-inflammatory effects [15]; at the Medical University of Vienna, Ferk and others verified that flavonoids in hops prevent the growth of cancer cells [16]; its moderate consumption aids in cardiovascular health, as presented by Constanzo and others [17]; beer reduces the probability of having kidney stones [18]; and even protects against Alzheimer's and cognitive impairment, according to an extensive research performed at Loyola University in Chicago [19].

Besides such benefits, this study aims to analyze different styles of beers and to evaluate if the concentration of Potassium-40 activity in them differ. Let's get down to the results:

Materials and Methods

The gamma-spectrometric analysis technique was used to determine the concentration of Potassium-40 activity in the beer samples. The IAEA-327-Soil Reference Material [20] was used for validation of the gamma-ray measurement method.

The potential of this technique permits the study of gamma emitters in a wide range of energy. In gamma spectrometry, germanium is used as a semiconductor material for the detection system. Hyperpure Germanium detectors (HPGe) are the most utilized because of the high-energy resolution and the possibility of identifying radionuclides that emit gamma radiation and determining their activities. The detectors are connected to multi-channel analyzers and appropriate software for identification and quantification of radionuclides [21].

An aliquot of approximately 280 grams of each beer was hermetically sealed in an acrylic jar for the quantification of the radionuclide.

A Gamma Spectrometry system, model GX2518 from Canberra Industries, with HPGe detector and Genie 2000 software was used for data acquisition and processing.

Results

The IAEA-327-Soil Reference Material [20] was analyzed for validation of the measurement method used. Table 1 presents the certified value for the determination of the concentration of Potassium-40 activity and the result of the analysis of the reference material, which was considered satisfactory.

Table 1 - Reference material results

Certified Concentration ($Bq.kg^{-1}$)	95% Confidence Interval ($Bq.kg^{-1}$)	Measured Concentration ($Bq.kg^{-1}$)
621	612 - 630	638 ± 27

Beer is a highly-disseminated drink of intense consumption, and can be produced from various raw materials. The main ingredients are water, barley, hops and yeast, and this variety of ingredients, as well as the inclusion of others, will differentiate them in styles.

In the present study, a variety of beers in different styles were analyzed, with a total of six different samples. In Table 2 and Figure 1, the results obtained from the concentration of Potassium-40 activity in beers are presented. The uncertainties presented are the standard deviation of measurements.

Table 2 - Concentration of Potassium-40 activity in beer samples

Style	Origin	^{40}K (Bq.kg-1)
Standard American Lager (SAL)	Netherlands	17.58 ± 2.78
Catarina Sour with Coffee (CSC)	Lauro Müller, SC.	13.32 ± 2.54
Russian Imperial Stout w/ Banana (RIS)	Poços de Caldas, MG.	34.80 ± 3.56
IPA (IPA)	Campo Bom, RS.	26.57 ± 3.22
Weissbeer (WEB)	Germany	20.30 ± 2.92
Schwartzbier (SCH)	Petrópolis, RJ.	24.64 ± 3.86

Note: Trademarks have been omitted to protect rights.

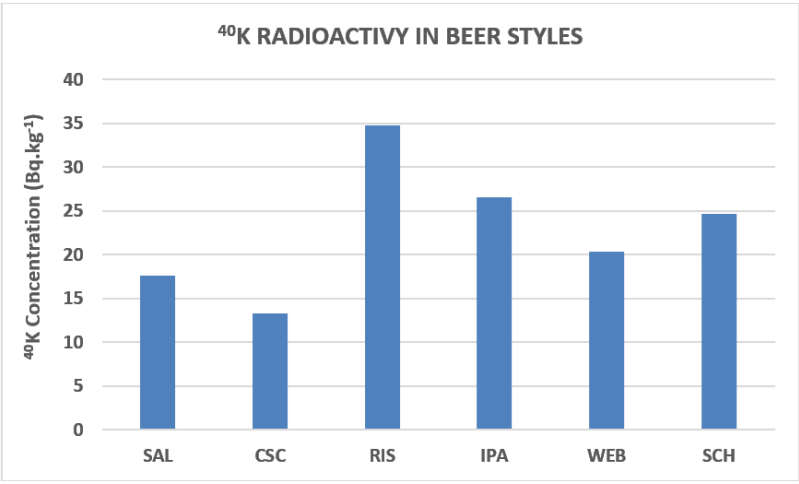

Figure 1 - Concentration of Potassium-40 activity in beer samples.

Potassium is an essential element for humans, and its concentration in the body is controlled by metabolic processes

[22]. It participates in the acid-base balance in the intracellular fluid, in the regulation of osmotic pressure, conduction of nerve impulses, muscle contraction, and cell membrane function. Its importance for human health continues being studied, emphasizing its positive effects and potential use in public health. A high intake of potassium has been shown to protect people from a number of conditions that affect the cardiovascular system, kidneys and bones [23].

The results of the concentration of Potassium-40 activity in the different styles of beers analyzed were compared by the average, with the value of 22.9 $Bq.kg^{-1}$ and standard deviation of 7.55 $Bq.kg^{-1}$ obtained, being able to conclude that there was a variation between the concentration values of potassium-40 activities in the different styles analyzed. Drinking one liter of beer corresponds, in average, to 15% to 20% of the daily intake of Potassium-40 for a normal adult.

Conclusion

After the analysis of six different styles of beers, it was possible to confirm that there were variations in the concentrations of Potassium-40 activities, which can be explained by the variety of ingredients in the production of such beers.

The world of beer is really fascinating: a plethora of new discoveries in the most unexpected areas and situations! Now you can impress your fellow brewers with this new information on radiation in beer: at the moment when you open an aging beer (aged in barrels, or even in the bottle), you can say “wow, this aroma of argon is marvelous!”...

References

[1] F. Cavalcante, *Avaliação da radioatividade natural e artificial em rações comerciais para animais domésticos*. Retrieved from <http://www.teses.usp.br/teses/disponiveis/85/85131/tde-16052017-112333/pt-br.php> (2017).

[2] R. Mehra, Radiological Risk Assessment in Soil Samples of Western Haryana, India. World Academy of Science, Engineering and Technology, Open Science Index 30, *International Journal of Physical and Mathematical Sciences*, 3(6), pp.448-452 (2009).

[3] Potassium 40, *Radioactivity.eu.com*. Retrieved from <http://www.radioactivity.eu.com/site/pages/Potassium_40.htm> (N/A).

[4] A. M. Helmenstine, 10 Common Naturally Radioactive Foods, *ThoughtCo*. Retrieved from <https://www.thoughtco.com/common-naturally-radioactive-foods-607456> (2018).

[5] Quora, Here's Why Every Glass Of Wine You Drink Is Radioactive - Yes, Really, *Forbes*. Retrieved from <https://www.forbes.com/sites/quora/2016/02/02/heres-why-every-glass-of-wine-you-drink-is-radioactive-yes-really/#5119b4a27015> (2016).

[6] K. Shilcutt, 8 Foods You Didn't Know Are Radioactive, *Houston Press*. Retrieved from <https://www.houstonpress.com/restaurants/8-foods-you-didnt-know-are-radioactive-6410052> (2010).

[7] D. Protopopescu, *Banana Equivalent Dose*. Retrieved from <https://www.ppe.gla.ac.uk/~protopop/teaching/NPP/P2-NPP.pdf> (2012).

[8] D. Biello, Is Radioactive Hydrogen in Drinking Water a Cancer Threat?, *Scientific American*. Retrieved from <https://www.scientificamerican.com/article/is-

radioactive-hydrogen-in-drinking-water-a-cancer-threat/> (2014).

[9] E. Inglis-Arkell, Drinking a Beer Can Save You From Radiation Poisoning, *Gizmodo*. Retrieved from <https://io9.gizmodo.com/drinking-a-beer-can-save-you-from-radiation-poisoning-1648955835> (2014).

[10] E.A. Varanda & D.C. Tavares, Radioprotection Mechanisms and Radioprotective Agents Including Honeybee Venom, *J Venom Anim Toxins*, Botucatu, 4(1), pp.5-21 (1998).

[11] C.K.K. Nair; D.K. Parida & T. Nomura, Radioprotectors in Radiotherapy, *J Radiat Res*, 42(1), pp.21–37 (2001).

[12] M. Monobe & K. Ando, Drinking beer reduces radiation-induced chromosome aberrations in human lymphocytes, J *Radiat Res*, 43(3), pp.237-245 (2002).

[13] M. Monobe; S. Koike; A. Uzawa; M. Aoki; N. Takai; T. Fukawa; Y. Furusawa & K. Ando, Radioprotective activities of beer administration for radiation-induced acute toxicity in mice, *Radiother Oncol*, 73 Suppl 2, pp. S127-129 (2004).

[14] M. Cornell, *A Short History of Hops*. Retrieved from <http://zythophile.co.uk/2009/11/20/a-short-history-of-hops/> (2009).

[15] J. Scherr; D.C. Nieman; T. Schuster; J. Habermann; M. Rank; S. Braun; A. Pressler; B. Wolfarth & M. Halle, Nonalcoholic beer reduces inflammation and incidence of respiratory tract illness, *Med Sci Sports Exerc*, 44(1), pp.18-26 (2012).

[16] F. Ferk; W.W. Huber; M. Filipic; J. Bichler; E. Haslinger; M. Misík; A. Nersesyan; B. Grasl-Kraupp; B. Zegura & S. Knasmüller, Xanthohumol, a prenylated flavonoid contained in beer, prevents the induction of preneoplastic lesions and DNA damage in liver and colon induced by the heterocyclic aromatic amine amino-3-methyl-imidazo[4,5-f]quinoline (IQ), *Mutat Res*, 691(1-2), pp.17-22 (2010).

[17] S. Costanzo; A. Di Castelnuovo; M.B. Donati; L. Iacoviello & G. Gaetano, Wine, beer or spirit drinking in relation to fatal and non-fatal cardiovascular events: a meta-analysis, *Eur J Epidemiol*, 26(11), pp.833-850 (2011).

[18] P.M. Ferraro; E.N. Taylor; G. Gambaro & G.C. Curhan, Soda and Other Beverages and the Risk of Kidney Stones, *CJASN*, 8(8), pp.1389-1395 (2013).

[19] Loyola University Health System, Moderate drinking may protect against Alzheimer's and cognitive impairment, study suggests, *ScienceDaily*. Retrieved from <www.sciencedaily.com/releases/2011/08/110816112134.htm> (2011).

[20] IAEA – International Atomic Energy Agency, *Reference Sheet: Reference Material IAEA-327 Radionuclides in Soil*. Retrieved from <http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/32/042/32042411.pdf> (2001).

[21] D.C. Lauria; N.S.F. Martins & R. Zenaro, Monitoração radiológica ambiental, *Instituto de Radioproteção e Dosimetria* – IRD, 1, p.166 (2007).

[22] IAEA – International Atomic Energy Agency, *TECDOC- 1788 - Criteria for Radionuclide Activity Concentrations for Food and Drinking Water*, Vienna, Austria, IAEA (2016).

[23] WHO - World Health Organization, *Guideline: Potassium Intake for Adults and Children*, Geneva, Switzerland, World Health Organization (WHO) (2012).

DETERMINATION OF POTASSIUM-40 IN SOME BEER STYLES

Ricardo B. Smith[1], Luan T. V. Cheberle[2], Mychelle M. L. Rosa[2] and Roberto Vicente[1]

1. INTRODUCTION

One of the great characteristics of the enormous variety of beers, in their styles, is the possibility of using the most different ingredients in their production: sky is the limit in the choice of ingredients, and it is up to the brewer to tailor the proportions and combinations in order to create a unique and pleasurable taste. But what would be your reaction if you read it, on a beer label, that it contains radiation? "Lo, how did such thing get here on the shelf?"

Technically speaking, every food is slightly radioactive [1] because any organic compound contains carbon, which naturally exists in a mixture of its isotopes, including Carbon-14, which is radioactive. The calculation of the $^{14}C/^{12}C$ ratio is used for Carbon-14 dating, a method for identifying the age of fossils [2].

In the United States, the measurement of radioactivity in alcoholic beverages is one of the best methods for quality control of the origin of alcohol in alcoholic beverages: in fact, non-radioactive alcoholic beverages in the United States are illegal; they should present at least 420 disintegrations per minute (DPM) for every 750 mL. That is because the US government established that alcohol for consumption must originate from vegetables and not from petroleum. But the two types of alcohol are exactly the same; there is only one reliable test: to measure its radioactivity. The carbon of natural alcohol is originated from plants, which absorb carbon from the atmosphere through carbon dioxide, which is radioactive due to the continuous bombardment of cosmic rays. The petroleum carbon also came from the atmosphere, but it was buried tens of millions of years ago, being isolated from atmospheric radioactivity. The radioactive carbon has a half-life of about 5,700 years, and after a hundred million years, it is almost impossible to have even one carbon-14 atom left [3].

And it is not only of ^{14}C that there are radioactive isotopes in food: in minimum proportions, a good part of the Periodic Table is also within our favorite dishes. An element that stands out is potassium, which is essential for the human being and which concentration in the body is controlled by the metabolism. Potassium-40, its radioactive isotope, is found in various vegetables and fruits, especially in bananas, papayas, beets, sweet potatoes, oats, almonds, among others. There is even an informal measurement for comparison of the radiation between different kinds of food: the Banana Equivalent Dose (BED), which is much simpler to understand than becquerels, sieverts, grays or rems. After all, is there anything more obvious than a banana? [4] A BED is equivalent to 0.1 microsievert in a radiation dose [5].

Damn, should I eat fewer bananas then? Actually, the difference between a medicine and a poison is in its dose: for you to absorb a high radiation dose from bananas, close to being lethal, you should have to eat something around 40,000,000 bananas. Do not try this at home. Anyway, beer surely tends to be far more attractive to be consumed in quantity than bananas; however, because of the alcohol in it, you will surely be asleep well before the first hundred thousand.

Actually, for millennia beer has been produced with beneficial effects for humans, especially after the introduction of hops in its manufacture, around the 12th and 13th centuries [6]. Later in the 21st century, further studies have reported several beneficial characteristics of this beverage: beer without alcohol has anti-inflammatory effects [7]; flavonoids in hops prevent the growth of cancer cells [8]; its moderate consumption aids in cardiovascular health [9]; beer reduces the probability of having kidney stones [10]; and even protects against Alzheimer's and cognitive impairment [11]!

Besides such benefits, this study aims to analyze different styles of beers and to evaluate if the concentration of Potassium-40 activity in them differ. Let's get down to the results:

2. MATERIALS AND METHODS

The gamma-spectrometric analysis technique was used to determine the concentration of Potassium-40 activity in the beer samples. The IAEA-327-Soil Reference Material [12] was used for validation of the gamma-ray measurement method. The potential of this technique permits the study of gamma emitters in a wide range of energy. In gamma spectrometry, Hyperpure Germanium detectors (HPGe) are the most utilized because of the high energy resolution and the possibility of identifying radionuclides that emit gamma radiation and determining their activities. The detectors are connected to multi-channel analyzers and appropriate software for identification and quantification of radionuclides [13].

An aliquot of approximately 280 grams of each beer was hermetically sealed in an acrylic jar for the quantification of the radionuclide. A Gamma Spectrometry system, model GX2518 from Canberra Industries, with HPGe detector and Genie 2000 software was used for data acquisition and processing.

3. RESULTS

The IAEA-327-Soil Reference Material [12] was analyzed for validation of the measurement method used. Table 1 presents the certified value for determination of the concentration of Potassium-40 activity and the result of the analysis of the reference material, which was considered satisfactory. In the present study, a variety of beers in different styles were analyzed, with a total of six different samples. In Table 2 and Figure 1, the results obtained from the concentration of Potassium-40 activity in beers are presented. The uncertainties presented are the standard deviation of measurements.

Potassium is an essential element for humans, and its concentration in the body is controlled by metabolic processes [14]. Its importance for human health continues being studied, emphasizing its positive effects and potential use in public health. A high intake of potassium has been shown to protect people from a number of conditions that affect the cardiovascular system, kidneys and bones [15].

The results of the concentration of Potassium-40 activity in the different styles of beers analyzed were compared by the average, with the value of 22.9 Bq.kg^{-1} and standard deviation of 7.55 Bq.kg^{-1} obtained, being able to conclude that there was a variation between the concentration values of potassium-40 activities in the different styles analyzed. Drinking one liter of beer corresponds, in average, to 15% to 20% of the daily intake of Potassium-40 for a normal adult.

Table 1: Reference material results

Certified Concentration (Bq.kg^{-1})	*95% Confidence Interval (Bq.kg^{-1})*	*Measured Concentration (Bq.kg^{-1})*
621	612 - 630	638 ± 27

Table 2: Concentration of Potassium-40 activity in beer samples

Style	*Origin*	*^{40}K (Bq.kg^{-1})*
Standard American Lager (SAL)	Netherlands	17.58 ± 2.78
Catarina Sour with Coffee (CSC)	Laura Müller, SC., Brazil	13.32 ± 2.54
Russian Imperial Stout with Banana (RIS)	Poços de Caldas, MG., Brazil	34.80 ± 3.56
India Pale Ale (IPA)	Campo Bom, RS., Brazil	26.57 ± 3.22
Weissbeer (WEB)	Germany	20.30 ± 2.92
Schwartzbier (SCH)	Petrópolis, RJ., Brazil	24.64 ± 3.86

Note: Trademarks have been omitted to protect rights.

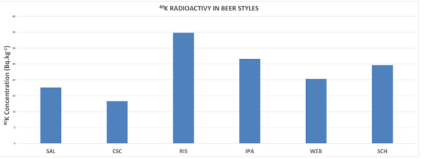

Figure 1: Concentration of Potassium-40 activity in beer samples.

4. CONCLUSION

After the analysis of six different styles of beers, it was possible to confirm that there were variations in the concentrations of Potassium-40 activities, which can be explained by the variety of ingredients in the production of such beers.

The world of beer is really fascinating: a plethora of new discoveries in the most unexpected areas and situations! Now you can impress your fellow brewers with this new information: at the moment when you open an aging beer (aged in barrels or in the bottle), you can say "wow, this radioactive aroma is marvelous!"...

REFERENCES

1. F. Cavalcante, "Avaliação da radioatividade natural e artificial em rações comerciais para animais domésticos", http://www.teses.usp.br/teses/disponiveis/85/8112/tde-16052017-112333/pt-br.php (2017).
2. A. M. Helmenstine, "10 Common Naturally Radioactive Foods", *ThoughtCo*, https://www.thoughtco.com/common-naturally-radioactive-foods-607656 (2018).
3. Quora, "Here's Why Every Glass Of Wine You Drink Is Radioactive – Yes, Really", *Forbes*, https://www.forbes.com/sites/quora/2016/02/02/heres-why-every-glass-of-wine-you-drink-is-radioactive-yes-really/#51198e127f19 (2016).
4. K. Shilcutt, "8 Foods You Didn't Know Are Radioactive", *Houston Press*, https://www.houstonpress.com/restaurants/8-foods-you-didnt-know-are-radioactive-6416051 (2010).
5. D. Protopopescu, "Banana Equivalent Dose", https://www.ppe.gla.ac.uk/~snelson/teaching/NPP/P2_NPP.pdf (2012).
6. M. Cornell, "A Short History of Hops", http://zythophile.co.uk/2009/11/20/a-short-history-of-hops/ (2009).
7. J. Scherr, D.C. Nieman, T. Schuster, J. Habermann, M. Rank, S. Braun, A. Pressler, B. Wolfarth, M. Halle, "Nonalcoholic beer reduces inflammation and incidence of respiratory tract illness", *Med Sci Sports Exerc*, **44(1)**, pp.18-26 (2012).
8. F. Ferk, W.W. Huber, M. Filipic, J. Bichler, E. Haslinger, M. Misik, A. Nersesyan, B. Grasl-Kraupp, B. Zegura, S. Knasmüller, "Xanthohumol, a prenylated d flavonoid contained in beer, prevents the induction of preneoplastic lesions and DNA damage in liver and colon induced by the heterocyclic aromatic amine amino-3-methyl-imidazo[4,5-f]quinoline (IQ)", *Mutat Res*, **691(1-2)**, pp.17-22 (2010).
9. S. Costanzo, A. Di Castelnuovo, M.B. Donati, L. Iacoviello, G. Gaetano, "Wine, beer or spirit drinking in relation to fatal and non-fatal cardiovascular events: a meta-analysis", *Eur J Epidemiol*, **26(11)**, pp.833-850 (2011).
10. P.M. Ferraro, E.N. Taylor, G. Gambaro, G.C. Curhan, "Soda and Other Beverages and the Risk of Kidney Stones", *CJASN*, **8(8)**, pp.1389-1395 (2013).
11. Loyola University Health System, "Moderate drinking may protect against Alzheimer's and cognitive impairment, study suggests", ScienceDaily, www.sciencedaily.com/releases/2011/08/110816111334.htm (2011).
12. IAEA – International Atomic Energy Agency, "Reference Sheet: Reference Material IAEA-327 Radionuclides in Soil", http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/32/042/32042411.pdf (2003).
13. D.C. Lauria, N.S.F. Martins, R. Zevaro, "*Monitoração radiológica ambiental*." *Instituto de Radioproteção e Dosimetria* – IRD, 1, p.166 (2007).
14. IAEA – International Atomic Energy Agency, *TECDOC- 1788 - Criteria for Radionuclide Activity Concentrations for Food and Drinking Water*, IAEA, Vienna, Austria (2016).
15. WHO - World Health Organization, *Guideline: Potassium intake for Adults and Children*, World Health Organization (WHO), Geneva, Switzerland (2012).

[1] Nuclear and Energy Research Institute (IPEN/CNEN–SP)
Av. Professor Lineu Prestes, 2242 - 05508-000 São Paulo, SP., Brazil
rbsmith@ipen.br / rvicente@ipen.br

[2] Ambientis Radioprotection
Av. Real, 236 - 06429-200 Barueri, SP, Brazil
luancheberle@gmail.com / my_linhares@yahoo.com.br