Canadian Nuclear Society

Salt Substitute as a radioactive source fact sheet

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$^{40}_{19}K$

Nu-Salt®, NoSalt®, or *Windsor® Salt Free*

Potassium-40 (^{40}K) is a naturally occurring radioactive isotope of the common element potassium (potassium represents about 2.4% by weight of the earth's crust). The half-life of ^{40}K is 1.248 x 10^9 years [1] — its origins are primordial. ^{40}K has an atomic percent abundance of 0.0117%. (^{39}K is 93.1% and ^{41}K is 6.88%, both are stable.)

$$^{40}K \xrightarrow[89\%]{} {}^{40}Ca + \beta^- + \overline{\nu}_e \qquad E = 1.311\,MeV$$

(Both ^{40}Ca and ^{40}Ar are stable, mean β^- energy of 560 keV)

$$^{40}K + e^- \xrightarrow[11\%]{} {}^{40}Ar + \nu_e \qquad E = 1.505\,MeV$$

$$\gamma = 1.46\,MeV$$

(either electron capture or β^+ decay (0.001%) produce ^{40}Ar with γ)

$$^{40}K \xrightarrow[0.001\%]{} {}^{40}Ar + \beta^+ + \nu_e$$

(mean β^+ energy of 0.24 MeV, β^+ annihilates when it interacts with an e^- emitting 2 γ of 0.511 MeV each in opposite directions)

The beta$^-$ particles having the maximum energy above have a range in water of about 1 cm. These interact with atoms to produce lower energy beta particles and low-energy gamma rays. The anti-neutrino and neutrinos carry a fraction of the energy. The electron capture results in the orbital electrons having an X-ray cascade with energies up to the maximum.

The ^{40}Ar / ^{40}K ratio in materials that trap argon such as solidified lava may be used for geological dating.

While potassium is a very common element, one does not usually find it in a concentrated, chemically "pure" form (except as potash in fertilizers). *Nu-Salt*®, *NoSalt*® and Windsor® *Salt Free* are dietary substitutes for common table salt, sodium chloride. Doctors recommend these products for <u>*some*</u> patients to reduce their sodium intake. (Note: potassium chloride is administered intravenously in some medical procedures to affect heart rate, and a *concentrated* solution is used for *execution by lethal injection* in some jurisdictions.)

These salt substitutes offer a convenient natural radioactive source for use in classroom demonstrations. They are readily available at low cost from grocery stores and pharmacies.

The FAQ page for *Nu-Salt*® has the following information [2]:

1. **What are the ingredients in *Nu-Salt*®?**
   Nu-Salt contains potassium chloride, potassium bitartrate, calcium silicate and natural flavor derived from citrus fruits and honey.

2. **What is the function of each ingredient?**
   Potassium chloride = is the salt substitute component of the blend.
   Potassium bitartrate = flavor modifier.
   Calcium silicate = anticaking agent.
   Natural flavor = taste modifier.

3. **Why does *Nu-Salt*® have such a high potassium content?**
   The minimum potassium requirement for adults is approximately 1600 to 2000 milligrams per day. The potassium content of Nu-Salt is 530 milligrams per 1/6 tsp. (1 g) serving which is approximately the same as the amount of potassium in one medium banana or one cup of fresh cantaloupe. Potassium chloride is used as a substitute for the common salt, sodium chloride.

Analysis

The *Nu-Salt* FAQ states that a (*large?*) banana has about 528 mg of potassium. The following table provides a list the potassium content of selected foods with the estimated activity (about 0.032 Bq per mg potassium).

Potassium Content and Potassium-40 Activity in Some Selected Foods				
Food	Portion	Potassium [mg]	K-40 [µg]	Activity [Bq]
Hot Dog	1 plain @ 98 g	143	16.7	4.5
Double Hamburger	1 loaded @ 226 g	570	66.7	18.1
Chicken, roasted	¼ @ 195 g (light & dark)	447	52.3	14.2
French Fries (veg. oil)	10 strips @ 50 g	306	35.8	9.7
Broccoli (raw)	3 spears @ 93 g	302	35.3	9.6
Brewed Coffee (black)	250 mL @ 250 g	135	15.8	4.3
Banana	1 medium @ 150 g	454	53.1	14.4
Orange juice, chilled	250 mL @ 263 g	500	58.5	15.9
2% Milk	250 mL @ 258 g	398	46.6	12.6
Skim Milk	250 mL @ 259 g	429	50.2	13.6
Figs, dried, uncooked	10 @ 137 g	1331	155.7	42.2
Potato, baked, skin on	1 @ 202 g	844	98.7	26.8
Bran Flakes, Post™	175 mL @ 37 g	177	20.6	5.6
Maple syrup	15 mL @ 20 g	41	4.8	1.3
Whole Wheat Bread	1 slice @ 28 g	71	8.3	2.3
White Bread	1 slice @ 25 g	30	4.0	1.0
Sunflower Seeds, dried	75 mL @ 41 g	345	40.4	10.9
Peanut Butter	30 mL @ 32 g	234	27.4	7.4
Egg	1 large @ 33 g	47	5.0	1.5

Source: Potassium concentrations from Health Canada, "Nutrient Value of Some Common Foods" http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/nutrient_value-valeurs_nutritives-eng.php

The 2.5 ounce *Nu-Salt*® canister has about 71 g of KCl. Approximately 34.7 g of the salt is potassium, or 0.96 gram-mole. The Nu-Salt canister is equivalent to about 66 "large" bananas and each banana is therefore a source of about 17 Bq (compared to 14 Bq in the table above).

The *Nu-Salt* canister has about 5.73×10^{23} potassium atoms, of which 6.7×10^{19} are ^{40}K. In 1.25×10^{9} years, half of these will have decayed, so at the present time, *on average* 1179 of the ^{40}K atoms in the container will decay in each second. This represents a radioactive source of 1.18 kBq.

The larger 311 g *NoSalt*® or Windsor ® *Salt Free* containers have about 2.8×10^{20} ^{40}K atoms, of which 4927 decay per second (*on average*) for an activity 4.93 kBq. (Note re Appendix exemption quantities: this corresponds to 15.9 Bq/g.)

A 70 kg person contains about 140 g of potassium [3] — or about 4 containers worth of the potassium in a 2.5 ounce *Nu-Salt* canister — or about 90% of the amount in the *NoSalt* / *Salt Free* container. This represents a source of about 4.44 kBq. ^{40}K is the dominant radionuclide in the human body, and delivers a dose of about 0.2 mSv per year [4]. The reference daily intake for potassium by an adult is 4.7 g [5] (149 Bq). Potassium is important to cell biochemistry. The potassium content of the body is normally regulated by homeostatic control [6]. People with reduced kidney function

have to regulate their potassium intake (a low-potassium diet instead of a low-sodium diet as practiced for control of high blood pressure).

Nu-Salt®, *NoSalt*® and *Windsor*® Salt Free are convenient radioactive sources for the classroom. See Appendix: Licensing of Radioactive Sources in Canada.

Nu-Salt® is a registered trademark of Cumberland Packing Corp., Brooklyn, New York 11205.
NoSalt® is a registered trademark of Joh. A. Benckiser, GmbH.
Windsor® Salt Free is a registered trademark of The Canadian Salt Company, Pointe-Claire, Quebec.

Another common source of concentrated potassium is chemical fertilizers. In this case the potassium is in the form of "soluble potash", K_2O. Lawn fertilizers such as 7-7-7 contain 7% by weight potassium oxide [7]. (Total nitrogen, the first number of the three is also 7% and does not include the other elements present in the nitrogen containing molecules.) Such fertilizer is a much weaker source of ^{40}K than potassium chloride at 18 kBq in a 10 kg bag of 7-7-7, or 1.8 Bq/g compared to ~16 Bq/g.

References:

[1] Interactive Chart of the Nuclides, www.nndc.bnl.gov/chart/

[2] Nu-Salt web page, www.nusalt.com

[3] Ed Uthman, M.D., "Elemental Composition of the Human Body," web2.iadfw.net/uthman/elements_of_body.html

[4] Radioactivity in Nature, Idaho State University; http://physics.isu.edu/radinf/natural.htm

[5] http://www.hc-sc.gc.ca/fn-an/nutrition/reference/table/ref_elements_tbl_e.html

[6] Potassium-40 – New Mexico State University phi.nmsu.edu/~pvs/teaching/phys593/potassium.pdf (originally from Argonne National Laboratory)

[7] http://www.iclfertilizers.com/Fertilizers/Knowledge%20Center/7-7-7.pdf

Suggestions for experiments:

1. How much mass area-density is required to reduce the excess count rate relative to background by half?

   (Hint: use thin sheets of low-Z materials such as paper or aluminum foil).

2. Using a known mass of KCl, measure the excess count rate. Calculate the radioactivity of this sample. Estimate the efficiency of your detector arrangement.

   (Hint: neglecting back-scattering from the table, normalize your counts by dividing by the ratio of the area of your detector window to the area of a sphere having a radius equal to the source-detector distance.)

   - What arrangement maximizes the efficiency?

COMMENTS? Please send us your comments on this fact sheet. ecc@cns-snc.ca

Example Procedure & Results:

To support the *Aware*® detector above the sample, use a shallow plastic cup of about the same diameter. For an RM-80, the plastic container from muffin cups is a convenient size.

1. Place a small amount of table salt (NaCl) — say ¼ teaspoon (1.25 mL). You may need a plastic bottle cap or other holder to make the diameter of the salt pile about the same as that of the detector window.

2. Determine the background count rate.

3. Replace the table salt with the same amount of KCl.

4. Determine the count rate.

5. Cut circles of thin aluminum foil to match the inside diameter of the support container.

6. Add the sheets of aluminum foil one at a time, and determine the count rates (at least 8).

7. Check the background count rate again when you are done.

8. Plot the count rate excess above background as a function of the number of foil disks.

   Note that this is a mixed-radiation field measurement. Both energetic electrons and gamma ray photons are detected. The energetic electrons are stopped in a small amount of aluminum. Gamma rays are less easily attenuated. You may see the count rate increase after the first minimum. Possible explanations include scattering of gamma rays generating a "dose build-up" of low energy electrons that interact with the counter more effectively than the gamma, or other scattering effects.

   Such graphs usually show “uncertainty bars”. What determines how large they should be?

Appendix Licensing of Radioactive Sources in Canada

The Canadian Nuclear Safety Commission (formerly the Atomic Energy Control Board) is the agency of the Government of Canada that is responsible for regulating the safe use of radioactive sources. SOR-2000 has been revised and now specifically references K-40.

The Nuclear Substances and Radiation Devices Regulations, (http://laws-lois.justice.gc.ca/eng/regulations/SOR-2000-207/FullText.html) Section 5 (1 a) stipulates that a licence is not required if the activity or activity concentration does not exceed the exemption quantities for licensing a radioactive source listed in “Schedule 1”. For ^{40}K the activity concentration is 1×10^2 Bq/g and the maximum activity is 1×10^6 Bq. As shown earlier, the KCl corresponds to 15.9 Bq/g. Hence so long as the total amount is less than 70 kg (202 canisters) the maximum activity would not be exceeded.

> Hence, for use as a radioactive source, one may possess a maximum of 202 *NoSalt*® or Windsor® *Salt Free* containers (65 kg) without having obtained a license from the CNSC.

The supply and consumption of KCl as a dietary alternative to NaCl is the subject of Health Canada regulations. The grocery stores, pharmacies, and consumers are not subject to the CNSC regulations as their possession of the material is not for use as a source of ionizing radiation.