



Friday, July 20

Report of Analysis:
Milford and Delta, UT Air Filter Samples

Performed for the
Desert Research Institute
Community Environmental Monitoring Program
[DRI-CEMP]

By the

University of Nevada, Las Vegas
Health Physics Department
Radiation Services Laboratory
[UNLV-RSL]

I. Narrative

Following contact with Mr. Jeff Tappen and Mr. Ted Hartwell of the Desert Research Institute (DRI) in Las Vegas, Nevada, it was arranged to send several air filter samples recently collected from the Milford and Delta, Utah, Community Environmental Monitoring Program (CEMP) stations to the University of Nevada - Radiation Services Laboratory (UNLV-RSL) for analysis by high-resolution gamma spectroscopy.

The laboratory designations used for the five air filters received are described below. Several unused “blank” filters were also provided by DRI for quality assurance/quality control purposes (QA/QC).

Sample Designations

AF-1/UNLV: Milford, UT CEMP Station # 036 (week ending 7/9/07)

AF-2/UNLV: Milford, UT CEMP Station #036 (week ending 7/9/07) – [duplicate]

AF-3/UNLV: Delta, UT CEMP Station # 083 (week ending 7/9/07)

AF-4/UNLV: Milford, UT CEMP Station # 036 (week ending 7/2/07)*

AF-5/UNLV: Delta, UT CEMP Station # 083 (week ending 7/2/07)

QA/QC [AF-B1, AF-B2, and, AF-B3: Background (unused) air filters].

* Note: an additional air filter sample (Milford duplicate filter for the week of 7/2/07) was also received, but only the primary air filter sample for this station was analyzed for this report.

II. Methods

Three co-axial, hyper-pure germanium detectors in the UNLV-RSL counting room (BHS-105) were calibrated using a mixed gamma reference standard over a useful energy detection range of approximately 50 keV to 2,000 keV (emission lines from Am-241: 59.5 keV through Y-88: 1836 keV). These three detectors were subsequently employed to perform overnight (1,000 minute) counts on each of the samples received. Analysis of the samples was carried out between July 13th and July 20th.

At the request of the client, the Milford Station air filter sample from the week of 7/9/07 (Sample AF-1/UNLV) was screened the same day it was received for the presence of naturally-occurring and man-made radioactivity, in particular the presence of Cs-137 — a man-made radioactive component of worldwide fall-out with a primary gamma-ray emission energy of approximately 662 keV.

The Milford sample from the preceding week (ending date 7/02/07) was also screened for 24-hours. Following these initial assessments, both of these priority samples and the remaining filters were counted for 1,000 minutes on one of the three detectors calibrated for this purpose (2” air filter counting geometry). A background filter was subsequently counted on each of the detectors used in the study.

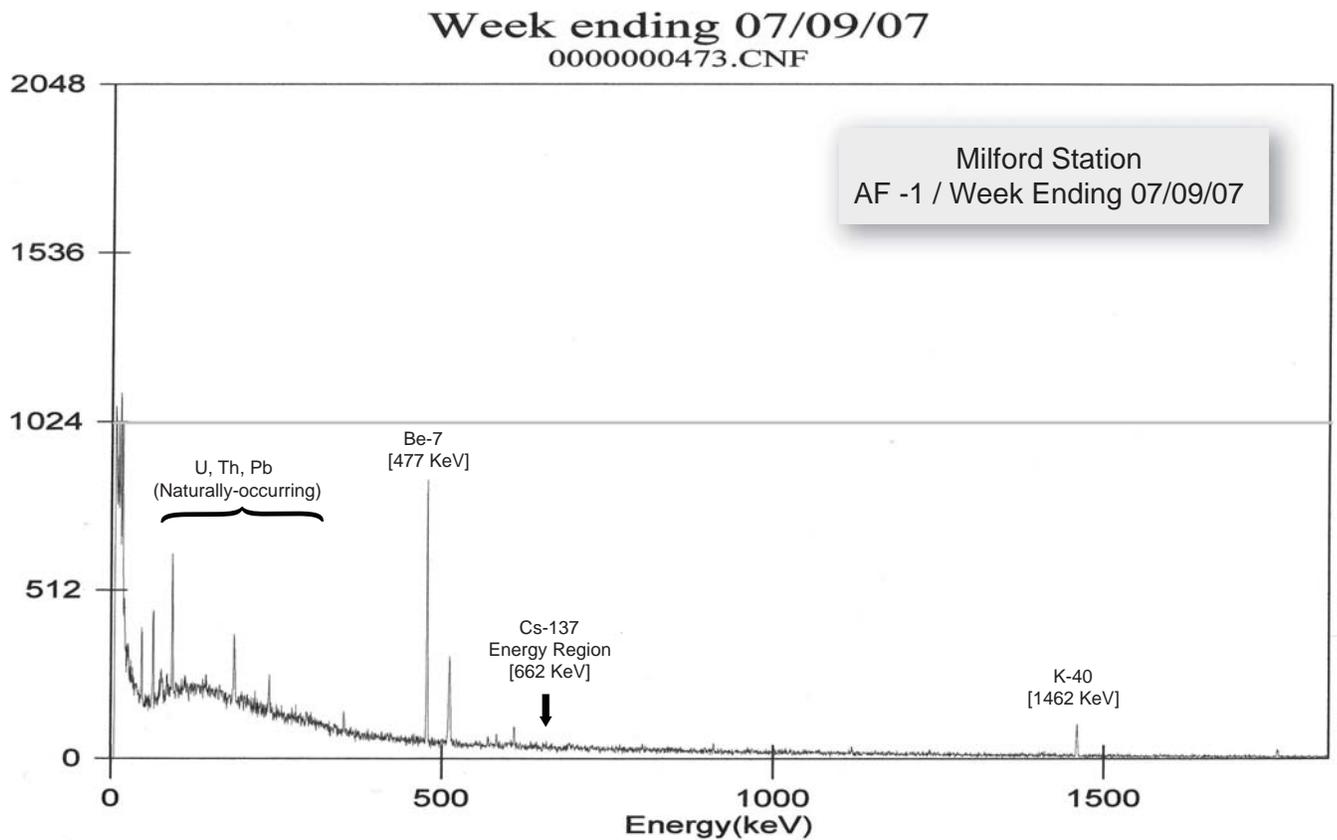
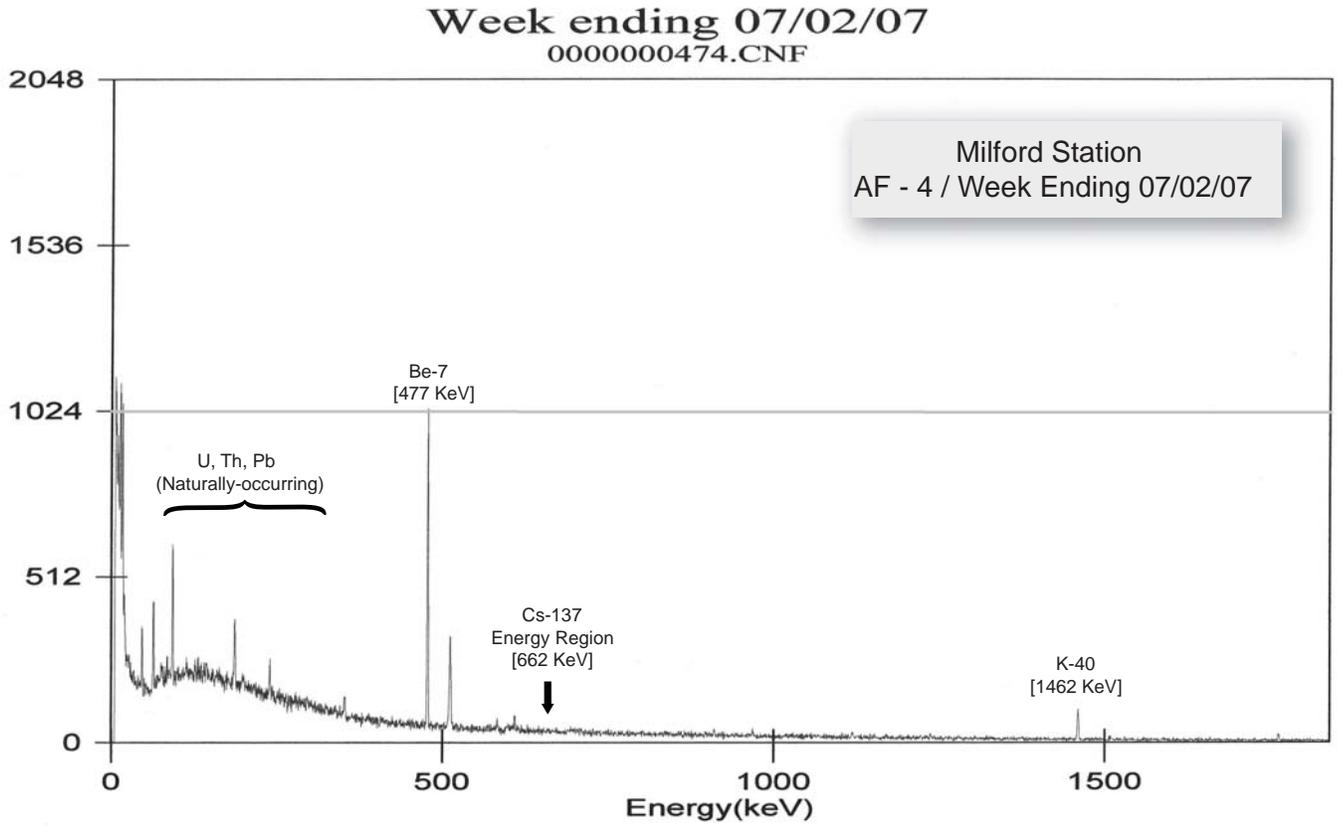
Individual results for each air filter are given in the section that follows (Table 1.) and discussed briefly in the final section — representative gamma-energy spectra have also been provided in Figure 1 of this report.

III. Analytical Results

Table 1. CEMP Gamma Counting Results (a), (b)												
[in Bq per filter]												
	STATION	Date On	Date Off	Collection Volume (c)	Be-7 [477KeV]	% error	Cs-137 [662keV]	% error	K-40 [1862 keV]	% error	Notes (d)	Det. (e)
AF-1/UNLV (2 nd AF)	Milford, UT (week ending 7/9/07)	07/2/07	07/9/07	686	5.20 ± 0.19	(4%)	-ND*	—	1.92 ± 0.17	(9%)	(Pb-212)	C_3
AF-2/UNLV (2 nd AF)	Milford, UT (week ending 7/9/07) - duplicate -	07/2/07	07/9/07	648	5.15 ± 0.20	(4%)	-ND-	—	2.07 ± 0.16	(8%)	(Pb-212) (Pb-214)	C_3
AF-3/UNLV (2 nd AF)	Delta, UT (week ending 7/9/07)	07/2/07	07/9/07	694	5.82 ± 0.21	(4%)	-ND-	—	2.29 ± 0.16	(7%)	(Pb-212) (Pb-214)	C_3
AF-4/UNLV (2 nd AF)	Milford, UT (week ending 7/2/07)	06/29/07	07/2/07	797	7.13 ± 0.26	(4%)	-ND-	—	2.21 ± 0.19	(9%)	(U-235)	C_1
AF-5/UNLV (2 nd AF)	Delta, UT (week ending 7/2/07)	06/29/07	07/2/07	690	6.72 ± 0.26	(4%)	-ND-	—	2.74 ± 0.19	(7%)	(Pb-212) (Bi-214)	C_2
AF-B1/UNLV (2 nd AF)	Background (7/18/07) - Matrix Blank -	N/A	N/A	(1)	-ND-	—	-ND-	—	2.27 ± 0.21	(9%)	(U235)	C_1
AF-B2/UNLV (2 nd AF)	Background (7/18/07) - Matrix Blank -	N/A	N/A	(1)	-ND-	—	-ND-	—	2.43 ± 0.19	(8%)	(Pb-212)	C_2
AF-B3/UNLV (2 nd AF)	Background (7/20/07) - Matrix Blank -	N/A	N/A	(1)	-ND-	—	-ND-	—	1.92 +/-0.16	(8%)	(Pb-212) (Pb-214)	C_3

- (a) Interference Corrected Report / Canberra Apex® Spectroscopy Software.
 (b) Minimum detectable activities (MDAs) for Cs-137 averaged 0.04 Bq/filter or approximately 1 picocurie (pCi).
 (c) Totalizer volumes from Station Manager data sheets: (volume in cubic feet X 0.0283 = cubic meters).
 (d) Natural peaks also identified in samples, but at levels below reliable quantification.
 (e) Gamma detector ID.
 * ND (not detected).

Figure 1.



IV. Discussion

Initial screening by gamma spectroscopy did not indicate the presence of unusual levels of man-made radionuclides in these filters. Cesium-137, a relatively long-lived component of worldwide fallout, was not detectable in any of the filter samples analyzed, either during the initial screening procedures (AF-1 & AF-4 / Milford Station) or in the subsequent routine counts (AF-1 through AF-5). The nominal minimum detectable activity for Cs-137, based on the instruments used and the counting times employed, is 0.4 Bq/filter or about 1 picoCurie (pCi).

The presence of several naturally-occurring radionuclides was identified in these samples. These included: Beryllium-7 (Be-7) a cosmogenically produced light radioisotope formed in the upper atmosphere; Lead-212 and Pb-214 (Pb-212/214) and several other species derived from the natural uranium and thorium decay series; and, Potassium-40 (K-40), which is present in atmospheric dust particles and virtually all other types of geological materials, and even in radiation shielding materials and cement flooring.

Uranium-235 (U-235) and Radium-226 (Ra-226) were also tentatively identified in these samples; however, these two natural species have gamma-emission energies at nearly the same energy (~ 186 keV) and are not generally listed as positively identified unless you can determine the proportion of each present in the sample. Their combined activity represents only a small fraction of the natural activity present in these samples (See attached Background References).

In summary, based on the filter collection volumes and the results reported here the activity of the most prominent gamma-emitting components in these samples are estimated to be about 8 to 10 mBq/m³ (Be-7) and 3 to 4 mBq/m³ (K-40). Other natural components are present only in variable and relatively small amounts, and no man-made radionuclides were detected.

V. Background References

1. Beryllium-7 and solar activity (in Applied Radiation and Isotopes, Vol. 61 (2004), pp 1493-1495).
 2. Natural Decay Series: Uranium, Radium, and Thorium: (from Argonne National Laboratory, EVS / Human Health Fact Sheet, August 2005).
 3. Potassium-40: (from Argonne National Laboratory, EVS / Human Health Fact Sheet, August 2005).
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[BACKGROUND MATERIAL: Beryllium-7]
3-pages

Beryllium-7 and solar activity

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Abstract

A very low concentration of ^7Be in air at Thessaloniki, Northern Greece ($40^\circ 38' \text{N}$, $22^\circ 58' \text{E}$) was recorded on November 9, 2003 following a strong event of solar wind that occurred on October 29, 2003.

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Keywords: Beryllium-7; Sunspots; Solar activity; Solar cycle

Beryllium-7 is a relatively short lived ($T_{1/2} = 53.3 \text{ d}$) naturally occurring radionuclide of cosmogenic origin, which is formed by spallation processes of light atmospheric nuclei, such as nitrogen ($Z = 7$), oxygen ($Z = 8$) and even carbon ($Z = 6$) when they absorb protons and even neutrons of the primary component of cosmic rays (Lal et al., 1958; Lal and Suess, 1968). It serves as an excellent tracer for upper and lower tropospheric sources and transport processes.

It is well known that the galactic cosmic-ray intensity at the earth's orbit is inversely related to solar activity (O'Brein, 1979). So, a decrease in the galactic cosmic-ray intensity has accompanied the recent increase in the solar activity, which will be followed by a decrease in the production rate of cosmic-ray products, such as Beryllium-7 that is therefore expected in a global scale.

This effect can be interpreted as follows: The solar wind is consistent with the relative low-energy particles eliminated the passage of the galactic cosmic radiation through the solar system to the earth and therefore it influences by reducing the production rate of cosmogenic origin radionuclides. A negative correlation is

therefore expected between the atmospheric Beryllium-7 and sunspots (Hötzl et al., 1991; Ioannidou and Papastefanou, 1994).

For more than 15 years, since 1987 air samples by filtering have been collected continuously at the Atomic and Nuclear Physics Laboratory, in the Aristotle University of Thessaloniki (Greece) to study the temporal and spatial distribution on specific natural and anthropogenic radionuclides in the surface air. Fig. 1 shows the variation of the sunspot number as an index of solar activity as registered by the NOAA Space Environment Center in Boulder, Colorado and the ^7Be concentrations in air as were recorded in Thessaloniki, Greece during the 15-year period starting from 1987. The sampling period was 24 h each time. The sample quantity was about 2800 m^3 of air and the flow rate was $\sim 2 \text{ m}^3 \times \text{min}^{-1}$ (68 cfm). The filter was glass fiber type TFAG810 of STAPLEX with dimensions $20.32 \text{ cm} \times 25.40 \text{ cm}$ ($8'' \times 10''$) and collection efficiency 95% of particles $0.5 \mu\text{m}$ and over. The gamma radioactivity of the filters was measured by a gamma-spectrometry system consisted of a high resolution (1.9 keV at 1.33 MeV) and high efficiency (42%) high-purity Ge detector and the uncertainty of the measurements was better than 8.5%. The inverse relationship between the ^7Be concentration in air and the sunspot number is clearly evident. The period that covered the data is quite larger than the 11-year solar cycle.

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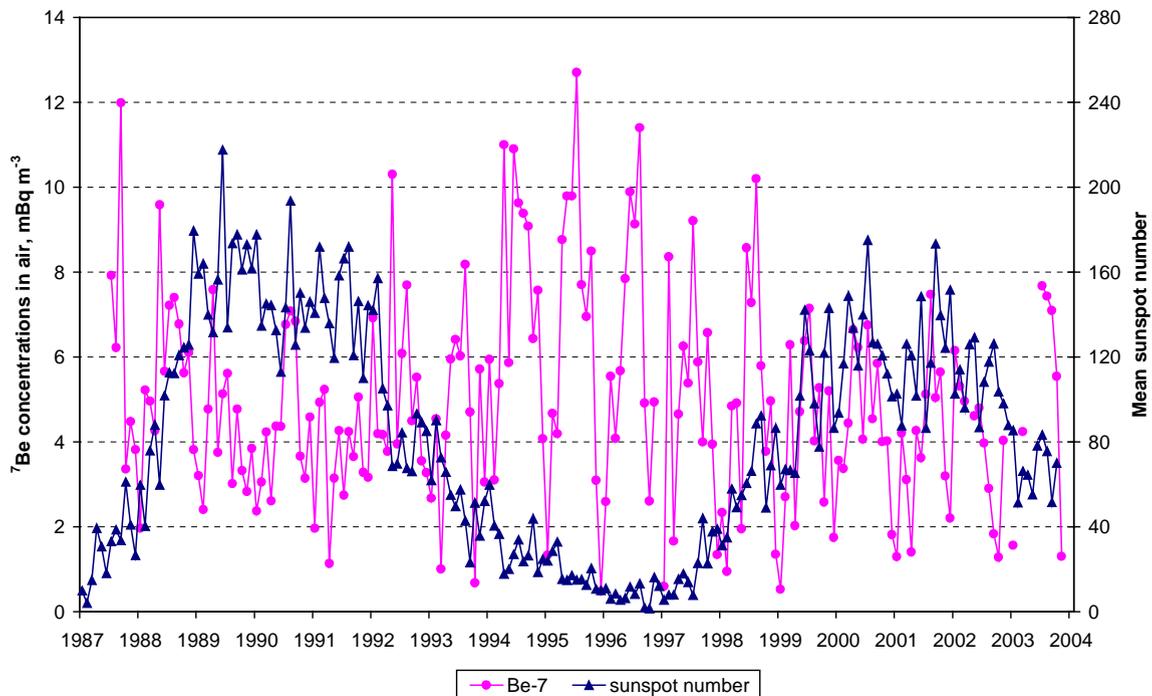


Fig. 1. Beryllium-7 and sunspot number at the period 1987–2003.

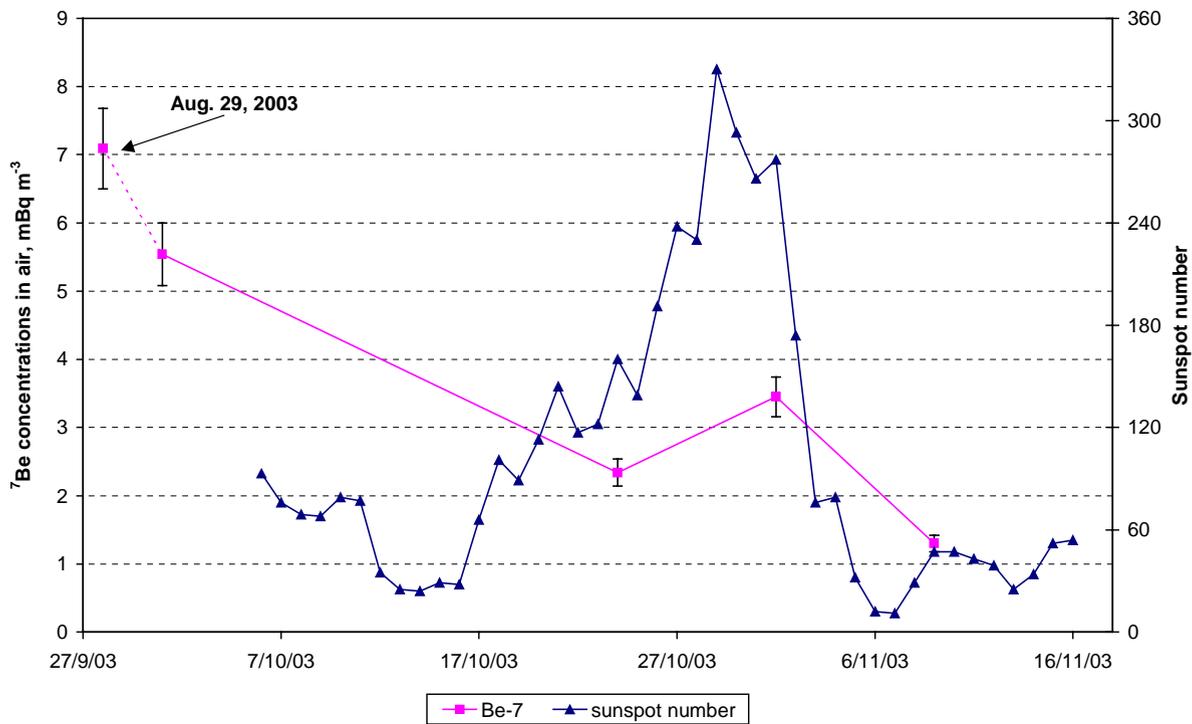


Fig. 2. Beryllium-7 and sunspot number at the period October–November 2003.

Recently on October 24, 2003, an event of strong solar wind accompanied by an increase of sunspot number has been occurred and followed by another event, the strongest one, on October 29, 2003 (sunspot number 330) seemed to affect the cosmic-ray intensity and resulted in a strong decrease of production rate of the cosmic-ray products leading to a very low-level concentration of ^7Be in air as low as $1.30 \pm 0.12 \text{ mBq m}^{-3}$, regarding the corresponding values observed from July 10 through October 2, 2003 at Thessaloniki, Northern Greece ($40^\circ 38' \text{N}$, $22^\circ 58' \text{E}$). Fig. 2 shows the ^7Be concentrations in air (four records) at Thessaloniki, Greece and the sunspot number as registered by NOAA for the months of October and November 2003. It is evident that the lowest value of ^7Be 1.30 mBq m^{-3} was recorded on November 9, 2003 and followed the highest value of sunspot number 330 which was registered on October 29, 2003. It must be noted that at the period of October–November 2003 in the 11-year solar cycle, as seeing at the curve of Fig. 1, we were at low sunspot number values and correspondingly at high ^7Be concentration values. These extraordinary events of solar

wind were followed by a geomagnetic storm, which influenced the electromagnetic emissions in the earth.

This paper really confirms the occurrence of the solar wind event.

References

- Hötzl, H., Rosner, G., Winkler, R., 1991. Correlation of ^7Be concentrations in surface air and precipitation with the solar cycle. *Naturwissenschaften* 78, 215–217.
- Ioannidou, A., Papastefanou, C., 1994. Atmospheric Beryllium-7 concentrations and sun spots. *Nucl. Geophys.* 8 (6), 539–543.
- Lal, D., Suess, H.E., 1968. The radioactivity of the atmosphere and hydrosphere. *Ann. Rev. Nucl. Sci.* 18, 407–434.
- Lal, D., Malhotra, P.K., Peters, B., 1958. On the production of radioisotopes in the atmosphere by cosmic radiation and their application to meteorology. *J. Atmos. Terr. Phys.* 12, 306–328.
- O'Brien, K., 1979. Secular variations in the production of cosmogenic isotopes in the earth's atmosphere. *J. Geophys. Res.* 84, 423–431.

[BACKGROUND MATERIAL: Natural Decay Series]
4-pages

Natural Decay Series: Uranium, Radium, and Thorium

Uranium, radium, and thorium occur in three natural decay series, headed by uranium-238, thorium-232, and uranium-235, respectively. In nature, the radionuclides in these three series are approximately in a state of secular equilibrium, in which the activities of all radionuclides within each series are nearly equal.

Two conditions are necessary for secular equilibrium. First, the parent radionuclide must have a half-life much longer than that of any other radionuclide in the series. Second, a sufficiently long period of time must have elapsed, for example ten half-lives of the decay product having the longest half-life, to allow for ingrowth of the decay products (*see the companion fact sheet on Ionizing Radiation*). Under secular equilibrium, the activity of the parent radionuclide undergoes no appreciable changes during many half-lives of its decay products.

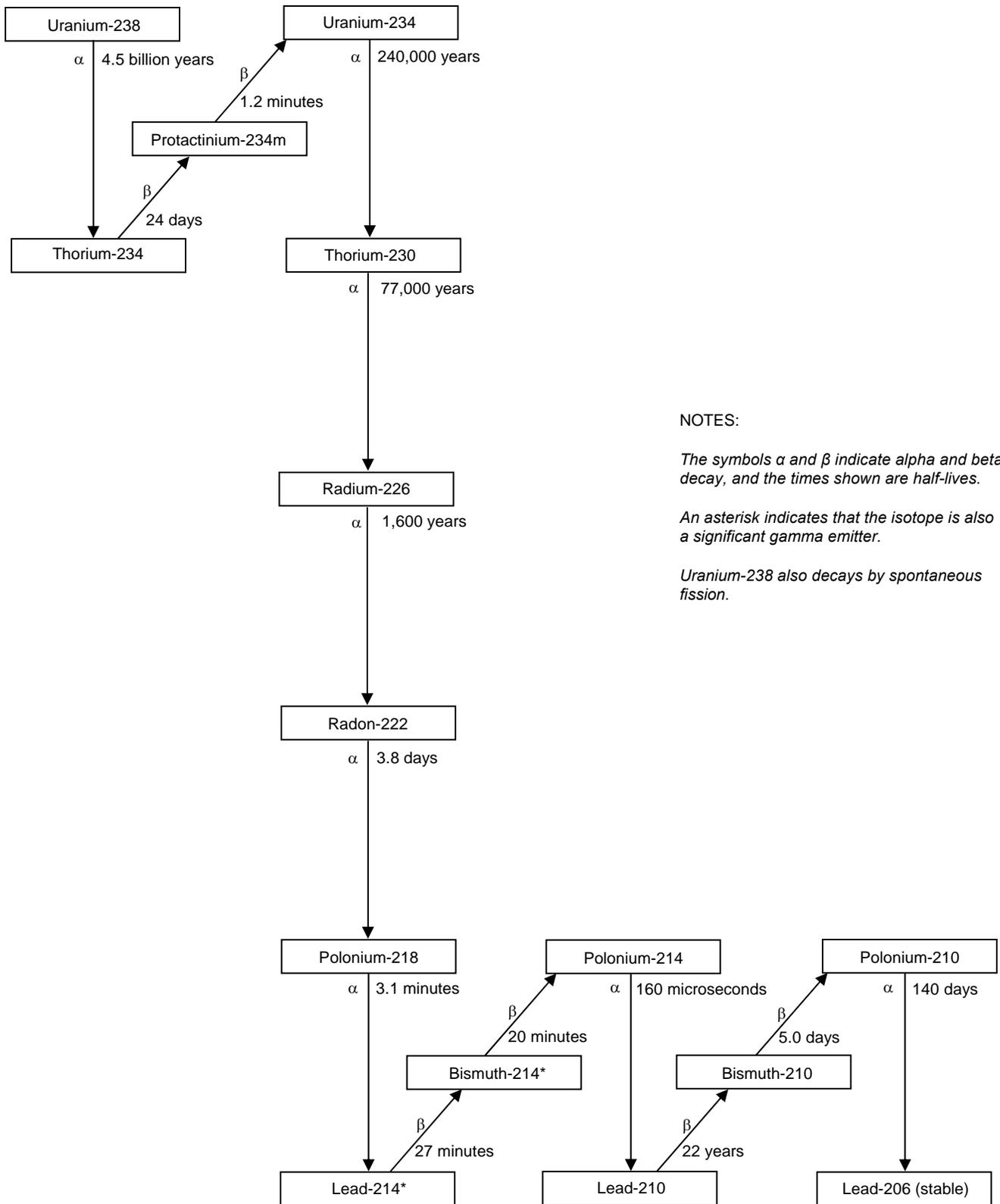
The radionuclides of the uranium-238, thorium-232, and uranium-235 decay series are shown in Figures N.1, N.2, and N.3, along with the major mode of radioactive decay for each. Radioactive decay occurs when an unstable (radioactive) isotope transforms to a more stable isotope, generally by emitting a subatomic particle such as an alpha or beta particle. Radionuclides that give rise to alpha and beta particles are shown in these figures, as are those that emit significant gamma radiation.

Gamma radiation is not a mode of radioactive decay (such as alpha and beta decay). Rather, it is a mechanism by which excess energy is emitted from certain radionuclides, i.e., as highly energetic electromagnetic radiation emitted from the nucleus of the atom. For simplicity, only significant gamma emissions associated with the major decay modes are shown in Figures N.1 through N.3; that is, radionuclides listed are those for which the radiation dose associated with gamma rays may pose a health concern. The gamma component is not shown for those radionuclides whose gamma emissions do not generally represent a concern.

Of the two conditions noted above for secular equilibrium, the first is generally met for the uranium-238, thorium-232 and uranium-235 decay series in naturally occurring ores. While the second condition may not be met for all ores or other deposits of uranium and thorium (given the extremely long half-lives for the radionuclides involved and the geological changes that occur over similar time scales), it is reasonable to assume secular equilibrium for naturally occurring ores to estimate the concentrations of the various daughter radionuclides that accompany the parent. The state of secular equilibrium in natural uranium and thorium ores is significantly altered when they are processed to extract specific radionuclides.

After processing, radionuclides with half-lives less than one year will reestablish equilibrium conditions with their longer-lived parent radionuclides within several years. For this reason, at processing sites what was once a single, long decay series (for example the series for uranium-238) may be present as several smaller decay series headed by the longer-lived decay products of the original series (that is, headed by uranium-238, uranium-234, thorium-230, radium-226, and lead-210 in the case of uranium-238). Each of these sub-series can be considered to represent a new, separate decay series. Understanding the physical and chemical processes associated with materials containing uranium, thorium, and radium is important when addressing associated radiological risks.

In the fact sheets developed for uranium, radium, and thorium, the contributions of radionuclides having half-lives less than one year were included in the risk coefficients. (Each fact sheet identifies which radionuclides are included in these coefficients.) In some situations, it may be necessary to add the radiological risk identified for a given radionuclide to that of its parent radionuclide to properly represent the total risk. For example, the radiological risk for thorium-232 is comprised of the risk for thorium-232 plus the risk for radium-228. Decay series information should be used together with the information in these fact sheets to ensure that the radiological risks associated with uranium, radium, and thorium are properly estimated and represented.



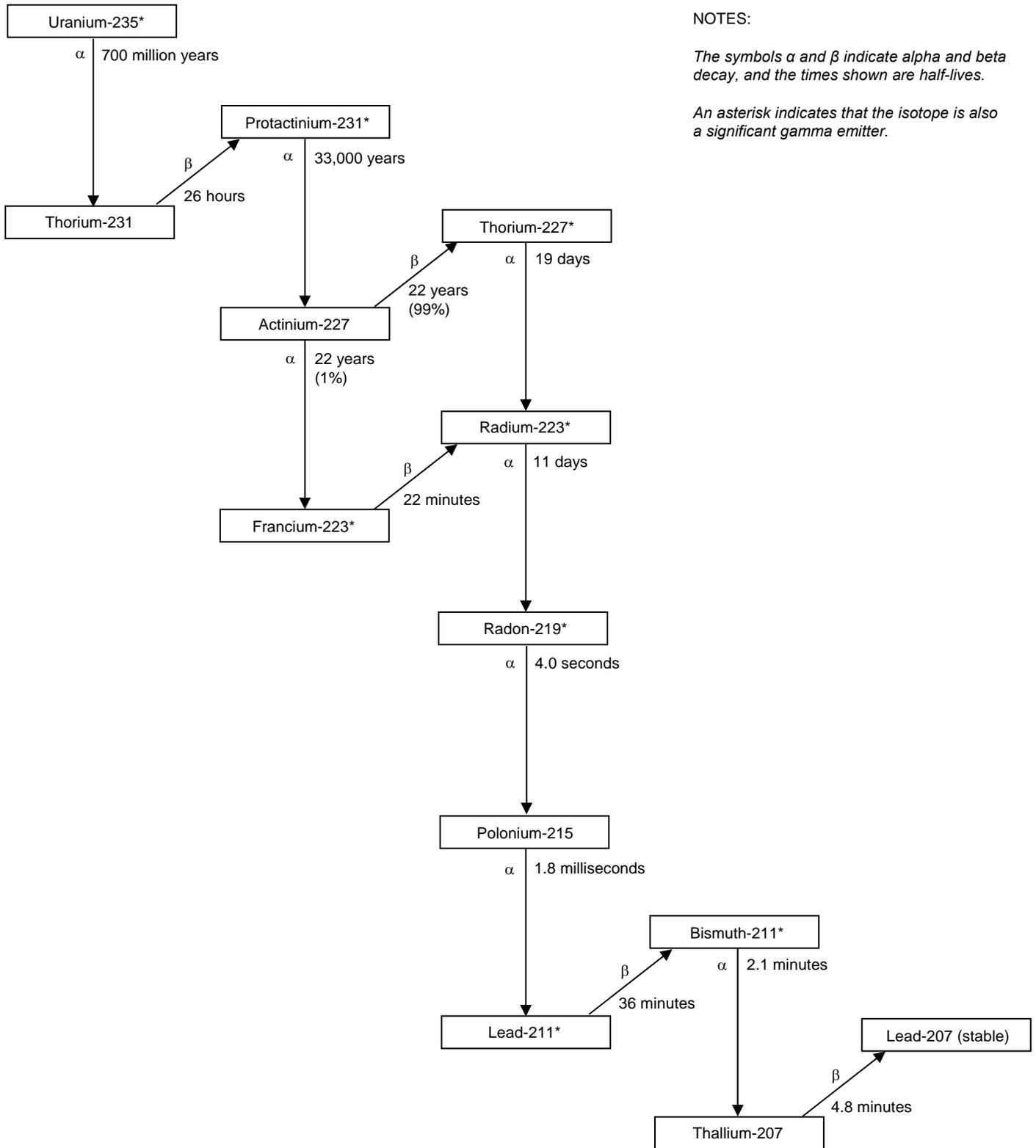
NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

Uranium-238 also decays by spontaneous fission.

FIGURE N.1 Natural Decay Series: Uranium-238



NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

FIGURE N.2 Natural Decay Series: Uranium-235

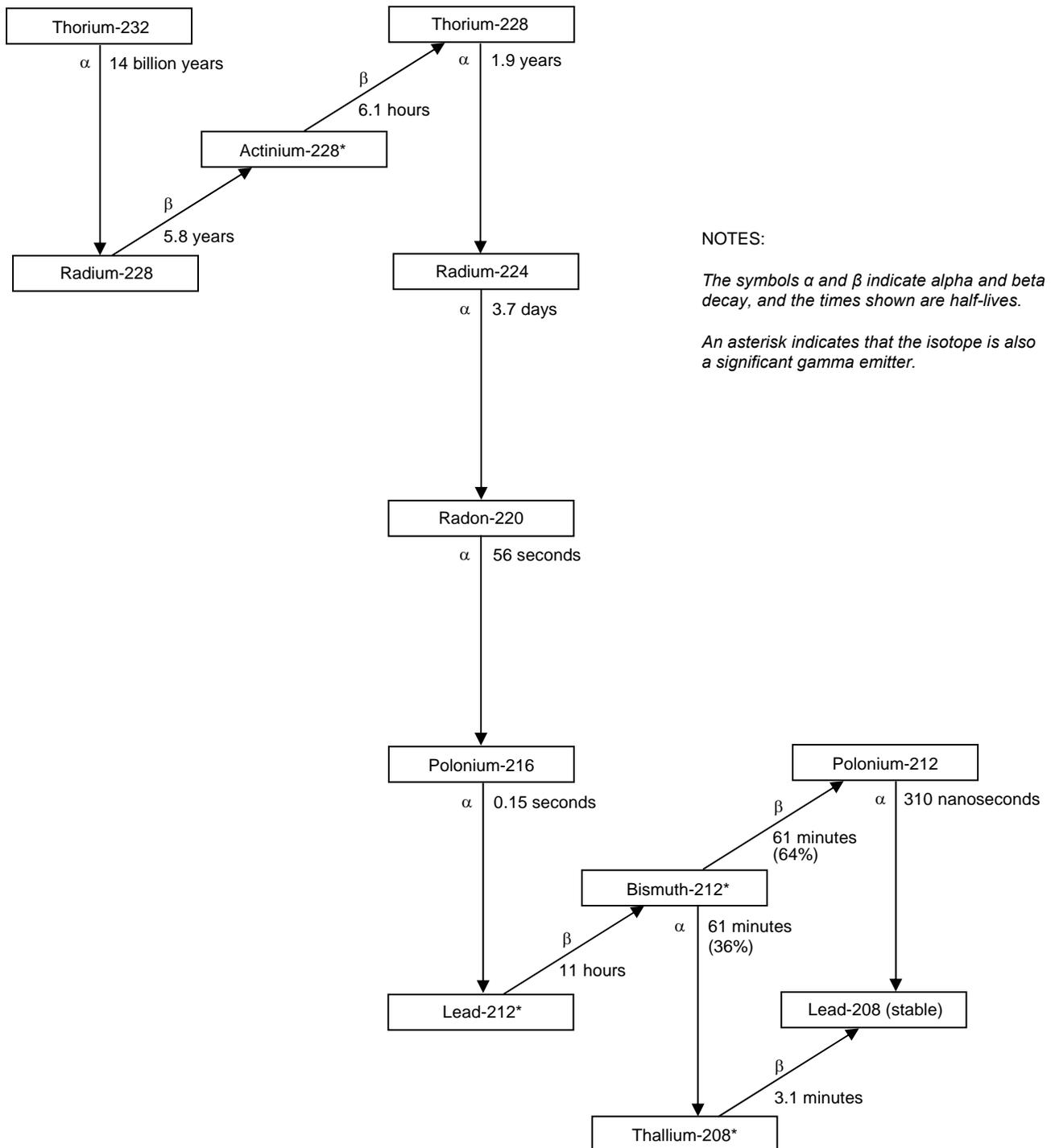


FIGURE N.3 Natural Decay Series: Thorium-232

[BACKGROUND MATERIAL: Potassium-40]
2-pages

Potassium-40

What Is It? Potassium is a soft, silver-white metal. An important constituent of soil, it is widely distributed in nature and is present in all plant and animal tissues. Potassium-40 is a naturally occurring radioactive isotope of potassium. (An isotope is a different form of an element that has the same number of protons in the nucleus but a different number of neutrons.) Two stable (nonradioactive) isotopes of potassium exist, potassium-39 and potassium-41. Potassium-39

Symbol:	K(-40)
Atomic Number: (protons in nucleus)	19
Atomic Weight: (naturally occurring)	39

comprises most (about 93%) of naturally occurring potassium, and potassium-41 accounts for essentially all the rest. Radioactive potassium-40 comprises a very small fraction (about 0.012%) of naturally occurring potassium.

Several radioactive isotopes of potassium exist in addition to potassium-40. These isotopes all have half-lives of less than one day so they are not of concern for Department of Energy (DOE) environmental management sites such as Hanford. The half-life of potassium-40

Radioactive Properties of Potassium-40

Isotope	Half-Life (yr)	Natural Abundance (%)	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
					Alpha (α)	Beta (β)	Gamma (γ)
K-40	1.3 billion	0.012	0.0000071	β , EC	-	0.52	0.16

EC = electron capture, Ci = curie, g = gram, and MeV = million electron volts; a dash means that the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for explanation of terms and interpretation of radiation energies.) Potassium-40 decays by both emitting a beta particle (89%) and electron capture (11%). Values are given to two significant figures.

is 1.3 billion years, and it decays to calcium-40 by emitting a beta particle with no attendant gamma radiation (89% of the time) and to the gas argon-40 by electron capture with emission of an energetic gamma ray (11% of the time). Potassium-40 is an important radionuclide in terms of the dose associated with naturally occurring radionuclides.

Where Does It Come From? Potassium-40 is present as a very small fraction of naturally occurring potassium, which is an element found in large amounts throughout nature. Potassium is the seventh most abundant element in the crust of the earth and the sixth most abundant element in solution in the oceans. It is present in mineral waters and brines, and in various minerals such as carnallite, feldspar, saltpeter, greensand, and sylvite. Potassium is an important constituent of fertile soil and is an essential nutrient for plant growth and in the human diet.

How Is It Used? Potassium metal, which is so soft it can be cut with a knife, is used in photoelectric cells. Potassium is one of the most reactive metals in nature, and it forms a number of compounds that have many commercial uses. For example, the white solid potassium bromide is used in photography, engraving, and lithography. The red crystal potassium chromate and yellow crystal potassium bichromate are powerful oxidizing agents used in matches and fireworks, and they are also used to dye textiles and tan leather. The white crystal potassium iodide is very soluble in water and is used in photography to prepare gelatin emulsions. It is also used in medicine to treat rheumatism and overactive thyroid glands. Potassium nitrate is a white solid used in matches, explosives, and fireworks, and it is also used to pickle meat. The purple crystal potassium permanganate is used as a disinfectant and germicide and as an oxidizing agent in various chemical reactions. The white solid potassium carbonate is used to make glass and soft soap. The white solids potassium sulfate and potassium chloride are used to fertilize soil, because potassium (along with nitrogen and phosphorous) is an essential element for plant growth. Potassium is also an essential element for humans, as a key electrolyte for maintaining basic cardiovascular functions; many people take potassium supplements as capsules or tablets. There are no specific commercial or medical uses associated with the radioactive properties of potassium-40.

What's in the Environment? Potassium is present in the earth's crust, oceans, and all organic material. Its concentration in the earth's crust is about 15,000 milligrams per kilogram (mg/kg) or 1.5%, and its concentration in seawater is about 416 mg per liter (mg/L). Because potassium-40 represents 0.012% of naturally occurring potassium, its concentration in the earth's crust is about 1.8 mg/kg, or 13 picocurie per gram (pCi/g). Potassium binds preferentially to soil, with the concentration associated with sandy soil particles estimated to be 15 times higher than in the interstitial water (in pore spaces between soil particles); it binds more tightly to loam and clay soil, so those concentration ratios are higher (above 50). Together with nitrogen and phosphorous, potassium is a major soil fertilizer, so levels of potassium-40 in soils are strongly influenced by fertilizer use; it is estimated that about 3,000 Ci of potassium-40 are added annually to U.S. soils. Potassium-40 behaves in the environment the same as other potassium isotopes, being assimilated into the tissues of all plants and animals through normal biological processes. It is the predominant radioactive component in human tissues and in most food. For example, milk contains about 2,000 pCi/L of natural potassium-40.



What Happens to It in the Body? Potassium-40 can be taken into the body by drinking water, eating food, or breathing air. Once taken in, potassium-40 behaves in the body in the same manner as other potassium isotopes. Humans require potassium to sustain biological processes, with most (including potassium-40) being almost completely absorbed upon ingestion, moving quickly from the gastrointestinal tract to the bloodstream. The potassium-40 that enters the bloodstream after ingestion or inhalation is quickly distributed to all organs and tissues. Potassium-40 is eliminated from the body with a biological half-life of 30 days. The potassium content of the body is under strict homeostatic control (in which the amount retained is actively regulated by the body to achieve the normal range required for system functions), and it is not influenced by variations in environmental levels. Hence, the potassium-40 content in the body is constant, with an adult male having about 0.1 microcurie or 100,000 pCi. Each year this isotope delivers doses of about 18 millirem (mrem) to soft tissues of the body and 14 mrem to bone.

What Is the Primary Health Effect? Potassium-40 can present both an external and an internal health hazard. The strong gamma radiation associated with the electron-capture decay process (which occurs 11% of the time) makes external exposure to this isotope a concern. While in the body, potassium-40 poses a health hazard from both the beta particles and gamma rays. Potassium-40 behaves the same as ordinary potassium, both in the environment and within the human body – it is an essential element for both. Hence, what is taken in is readily absorbed into the bloodstream and distributed throughout the body, with homeostatic controls regulating how much is retained or cleared. The health hazard of potassium-40 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the general potential for subsequent cancer induction.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including potassium-40 (see box at right). While ingestion is generally the most common type of exposure, the risk coefficients for this route are lower than those for inhalation. As for other radionuclides, the risk coefficient for tap water is about 70% of that for dietary ingestion. In addition to risks from internal exposures, an external gamma exposure risk also exists for potassium-40. To estimate a lifetime cancer mortality risk, if it is assumed that 100,000 people were continuously exposed to a thick layer of soil with an initial average concentration of 1 pCi/g potassium-40, then 4 of these 100,000 people would be predicted to incur a fatal cancer over their lifetime. (This is in comparison to the 20,000 people from the group predicted to die of cancer from all other causes per the U.S. average.)

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. Maximum values are given for inhalation since no default absorption types were provided, and dietary values were used for ingestion. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders (10^9 is a billionth, and 10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation (pCi ⁻¹)	Ingestion (pCi ⁻¹)
Potassium-40	2.1×10^{-10}	2.2×10^{-11}

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and the accompanying Table 1.

(This is in comparison to the 20,000 people from the group predicted to die of cancer from all other causes per the U.S. average.)