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Title: NSDD Flavor Drill July 2022 Answers

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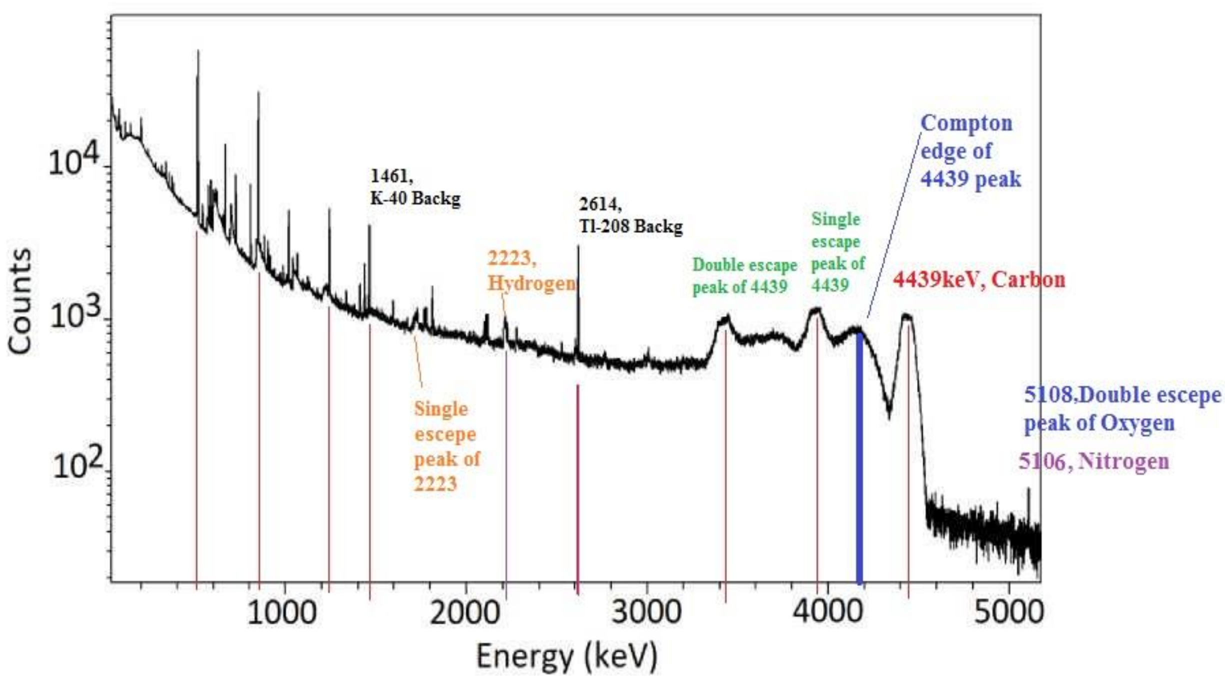
Thank you to the Azerbaijani team, who provided some of the graphics and discussion included below.

Question 1: A spectrum collected from a neutron source appears below. The source is most likely:

(A) Cf-252
(B) AmLi
(C) AmBe



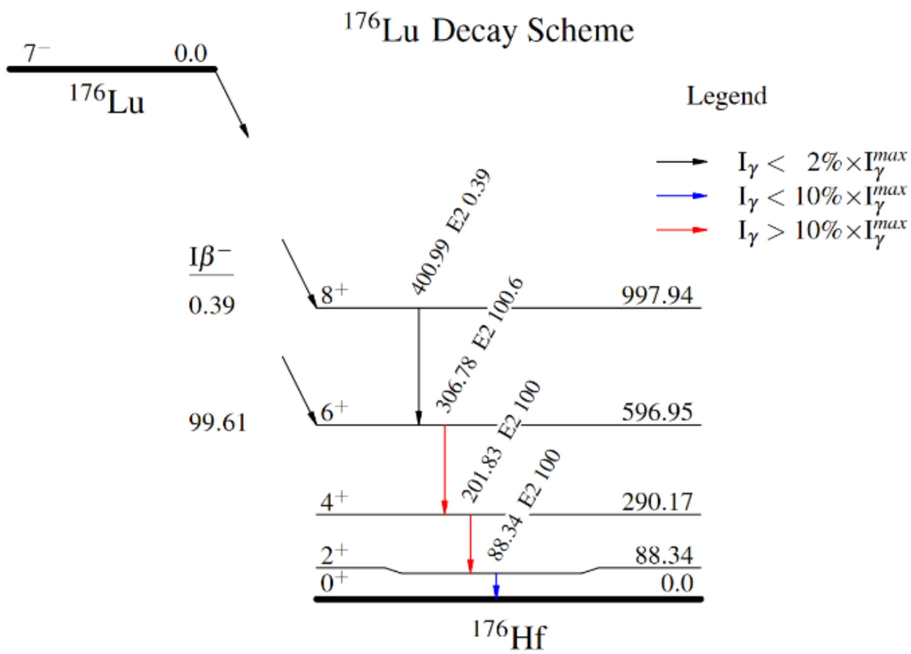
The structure above 3000 keV is characteristic of 9Be(α,n)12C* reactions that produce a 4438.9 keV excited state which then decays. The half-life of this state is short (about 40 fs) so the associated gamma ray experiences Doppler broadening (see Question 10). The gamma ray energy is incompletely captured, resulting in single- and double- 511 keV escape peaks.

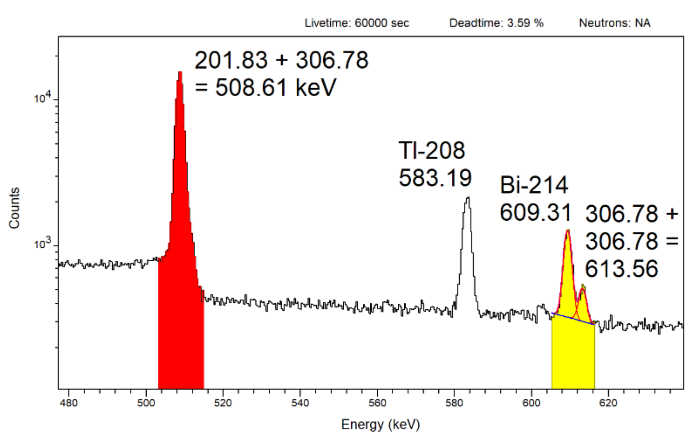
Question 2: The diagram and spectrum below represent the decay of Lu-176. A peak highlighted in red appears at 508.6 keV. This peak is mostly due to:

(A) Random (Accidental) Coincidence Summing

(B) Cascade (True) Coincidence Summing

(C) Positron Annihilation



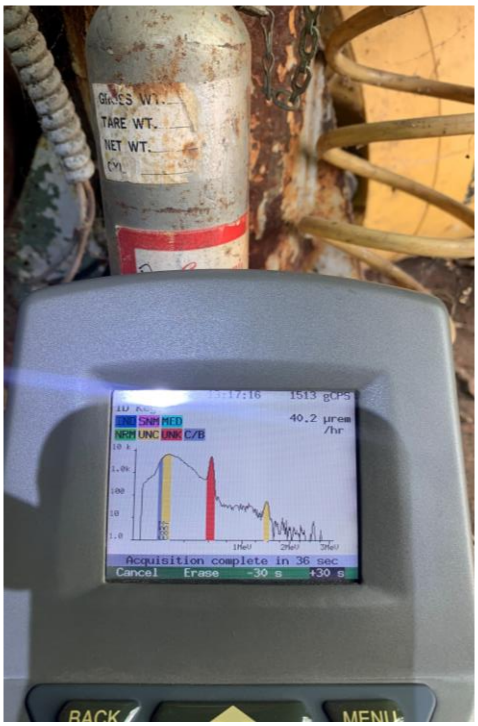


The peak at 508.6 keV is mostly due to cascade summation: 306.78 + 201.83 = 508.61 keV. The measurement was made with the source very close to the detector, which provides efficiency high enough to capture the two gamma rays that are emitted almost simultaneously.

Random summing is also present: a small random sum peak at 306.78 + 306.78 = 613.56 keV is resolved (rightmost peak above). The 306.78 + 201.83 keV random sum peak also exists, but has exactly the same energy as the cascade sum peak. It has roughly the same amplitude as the 613.56 keV peak, and contributes roughly 1.6% of the total area of the 508.61 keV peak.

Question 3: This old gas bottle was found in an abandoned warehouse associated with a company that manufactured specialty light bulbs. The spectrum shows peaks at 514 keV and 1460 keV. The radionuclide most likely present in the bottle is:

(A) F-18
(B) Na-22
(C) Kr-85
(D) Sr-85



Krypton gas containing Kr-85 (10.7 year) is used as a starting aid in high-intensity discharge lamps and electrodeless induction lamps. It is generally mixed with argon, neon, and/or xenon. It emits a 514 keV gamma ray.

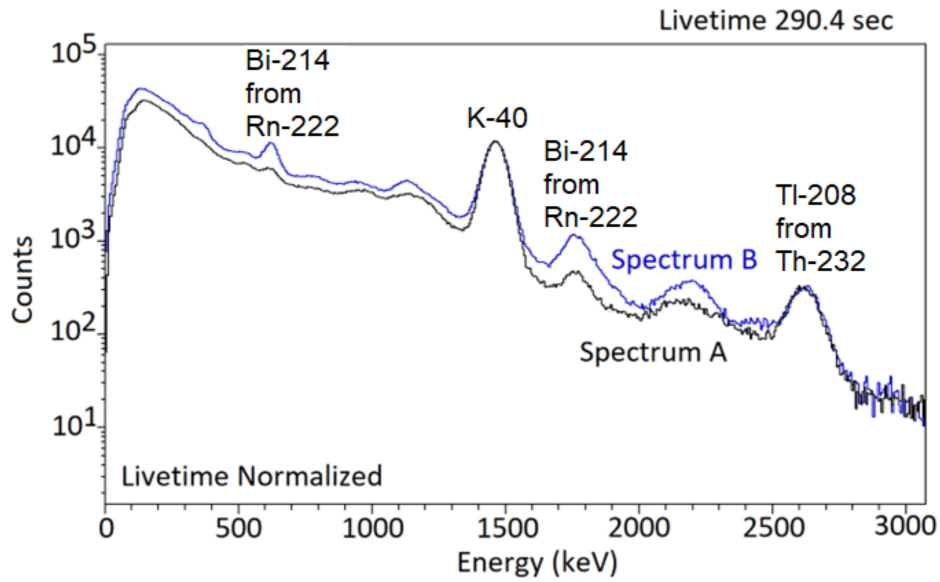
F-18 (1.83 hour) is gaseous but can be ruled out due to its short half-life and the fact that the bottle is "old". The 511 keV line from F-18 can be challenging to discriminate from 514 keV.

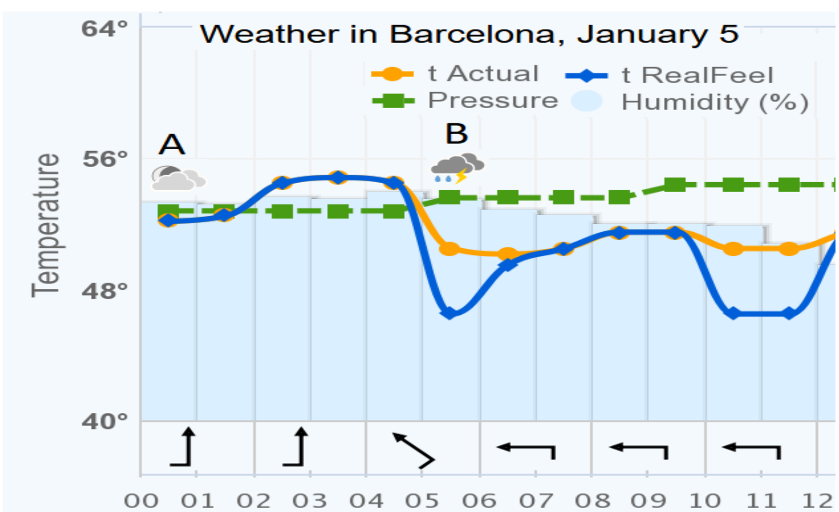
Na-22 (2.6 year) is not gaseous and unlikely to be found in a gas mixture. Although it emits a 511 keV gamma ray, Na-22 can be ruled out because it also emits a strong 1274.5 keV gamma ray that is not observed. Sometimes it is necessary to interpret a photograph of a spectrum; note the nonlinear energy scale for this instrument.

Sr-85 (64.8 days) is not gaseous and can probably be ruled out due to its short half-life. Spectroscopically it is almost identical to Kr-85. It may be observed as an impurity in Sr-82.

Question 4: The two background spectra shown below were collected in Barcelona, Spain with a large-volume NaI detector. Spectrum A (lower) was collected at 12:10 am before a rainstorm, and Spectrum B (upper) was collected at 5:40 am at the beginning of the rainstorm. Which radionuclide appears have an activity that depends on the weather?

(A) K-40
(B) Rn-222
(C) Th-232

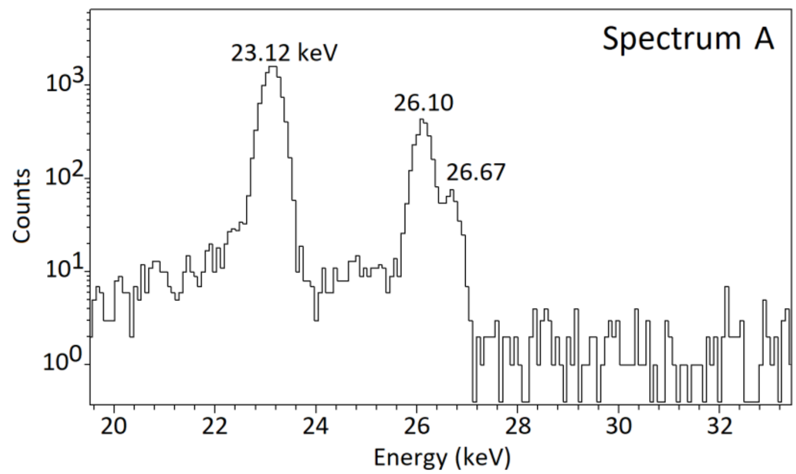


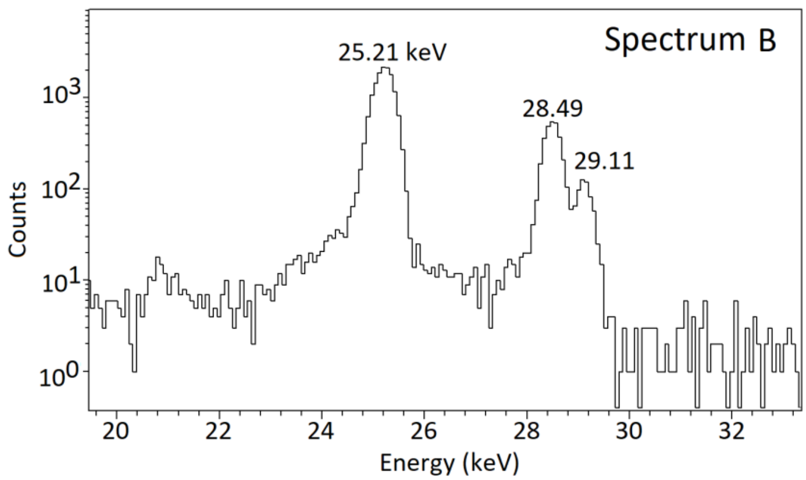


The Rn-222 daughter Bi-214 is more intense in Spectrum B, while K-40 and the Th-232 daughter Tl-208 do not change in intensity. Changes in weather can affect the transport of radon from soil into the atmosphere. Rainwater can also contain a concentration of radon.

Question 5: The two spectra below show fluorescent X-rays from cadmium (Cd) and tin (Sn). Fit values for three peaks are shown. Which spectrum shows cadmium (Cd) X-rays?

(A) Spectrum A
(B) Spectrum B





Cadmium (Cd) has a atomic number of 48, and tin (Sn) has an atomic number of 50. X-rays energies tend to increase with increasng atomic number, so Spectrum A must be cadmium because the observed energies are lower.

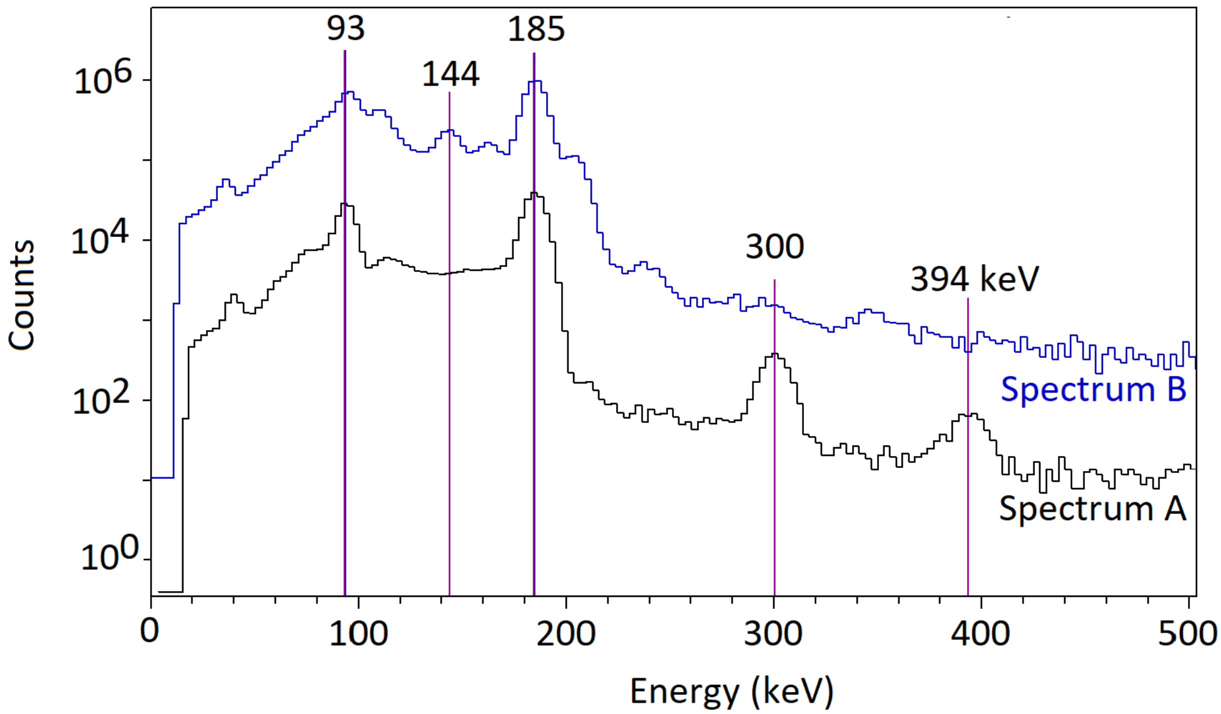
A table of X-ray energies and approximate relative intensities appears below (from Zschornak). Kα1 and Kα2 lines are not resolved from each other in the spectra above.

X-ray line	Cd		Sn	
	Energy (keV)	Intensity	Energy (keV)	Intensity
Kα1	23.174	3.23	25.271	3.83
Kα2	22.984	1.72	25.044	2.08
Kβ1	26.095	0.55	28.486	0.67
Kβ2	26.664	0.09	29.109	0.12

Question 6: The spectra below are collected from highly-enriched uranium (HEU) and Cu-67 using a lanthanum bromide (LaBr3) detector. Which spectrum is from HEU?

(A) Spectrum A

(B) Spectrum B



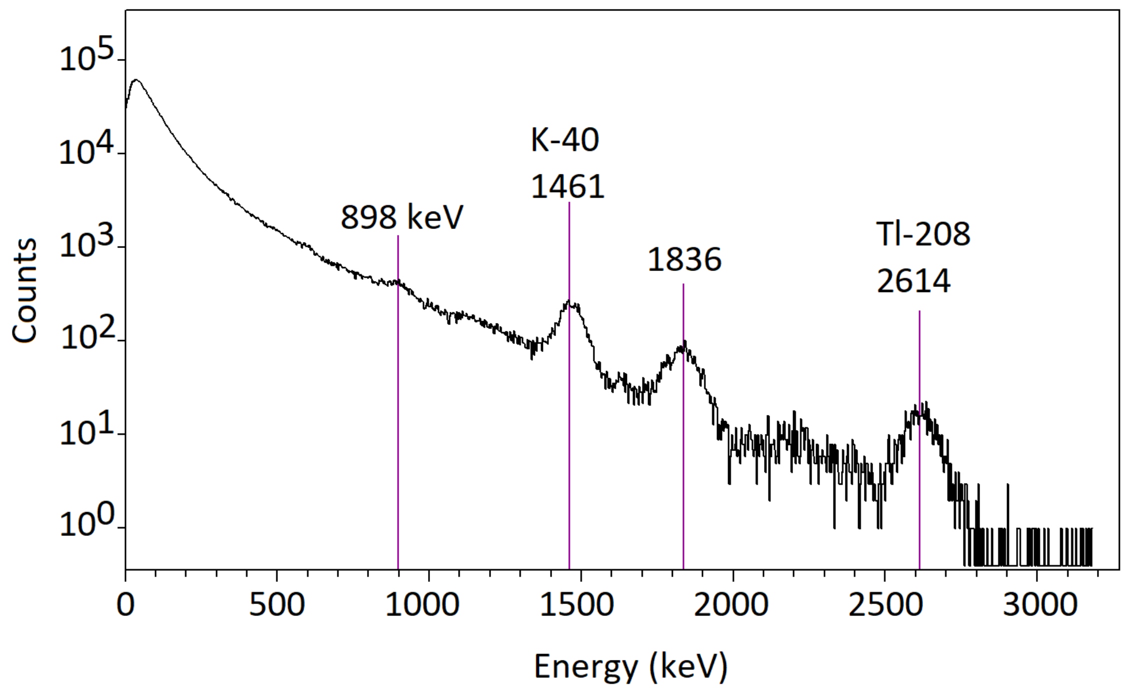
Spectrum A is HEU and Spectrum B is Cu-67. 144 keV is a characteristic energy of U-235 (present in HEU). 300 and 393.5 keV are characteristic energies of Cu-67.

A 205 keV peak from U-235 and a 239 keV peak from Pb-212 are also visible in Spectrum A. The Pb-212 comes from a U-232, which is an impurity in this sample.

These spectra were provided by Argonne National Laboratory.

Question 7: This spectrum was collected from a person who had received the radio-pharmaceutical Therasphere™ for treatment of liver cancer. An impurity radionuclide with a half-life longer than 100 days produces peaks visible at 898 and 1836 keV. What is this impurity?

(A) Eu-154
(B) Ho-166
(C) Rb-88-
(D) Tl-207
(E) Y-88



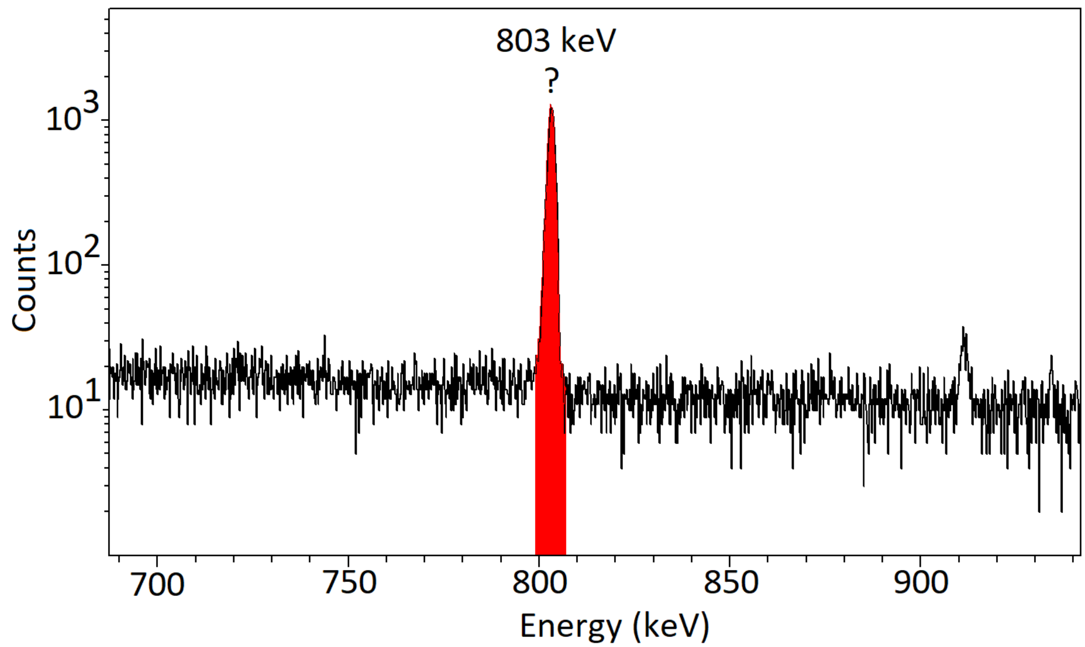
Y-88 (106 day) produces peaks at 898.04 and 1836.06 keV. It is a known impurity in Therasphere™ and is often visible in medical patients long after the Y-90 (64 hour) therapeutic radionuclide has decayed away.

The Azerbaijan team reported that Y-88 was visible in Y-90 microsphere waste after 4 months of storage at an oncology center.

Eu-152 (13.6 year), Eu-154 (8.8 year), Co-57 (272 day), and Co-60 (5.3 year) are also sometimes observed as impurities in Therasphere™.

Question 8: The radionuclide shown in the HPGe spectrum below decays by alpha emission, and approximately 0.001% of decays also produce a gamma-ray at 803 keV. It is used in static eliminators, thermoelectric generators, and heaters (especially in spacecraft). It is highly toxic and has been used for homicide. What is this radionuclide?

(A) Am-241
(B) Bi-206
(C) Cs-134
(D) Po-210



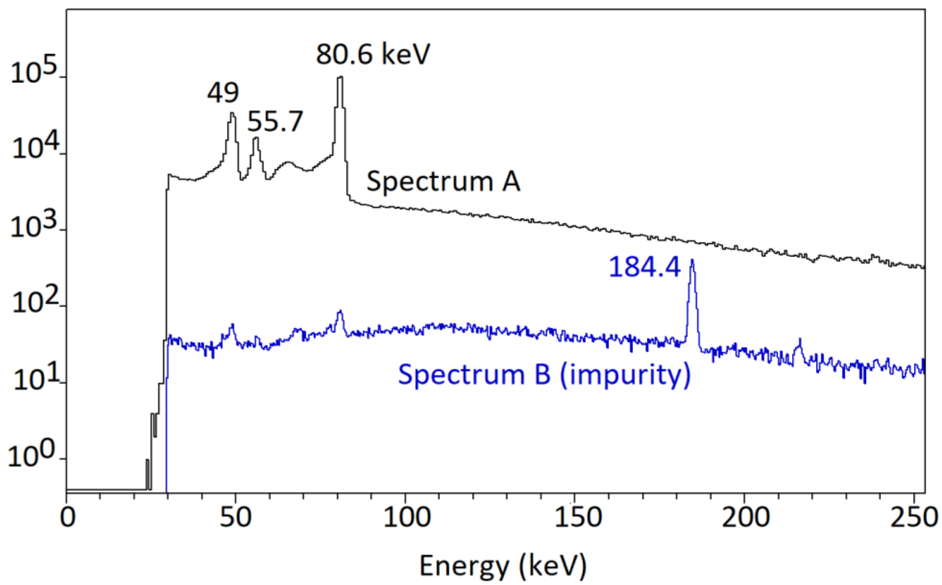
Po-210 (138 day) emits a gamma ray at 803.10 keV but no other gamma rays. The weak signature may be challenging to detect.

Bi-206 emits a gamma ray at 803.1 keV, but it also emits a strong gamma ray at 881.01 keV that is not observed in the spectrum above. It has no known medical or industrial uses and has very limited scientific applications.

Cs-134 emits a gamma ray at 604.72 keV that is sometimes misidentified as Po-210. It also emits a strong gamma ray at 795.86 keV that is not onserved in the spectrum above.

Question 9: This radionuclide emits gamma rays at 80.6 keV and x-rays at ≈49.1 keV and 55.7 keV as shown in Spectrum A below. It is used in a few uncommon radiopharmaceuticals. Depending on the method of production, a long-lived metastable impurity may also be present. This impurity produces gamma rays at 184.4 keV that are close to a characteristic energy of U-235. What is the radionuclide?

(A) Ga-67
(B) Ho-166
(C) Lu-177
(D) Tl-201
(E) Xe-133



Ho-166 (1.12 day) is used in a variety of radiopharmaceutical products and emits an 80.57 keV gamma ray and X-rays near 49 and 55.7 keV. These X-ray energies are characteristic of the erbium (Er) daughter and result from internal conversion electrons that leave k-shell holes in the daughter's atomic structure.

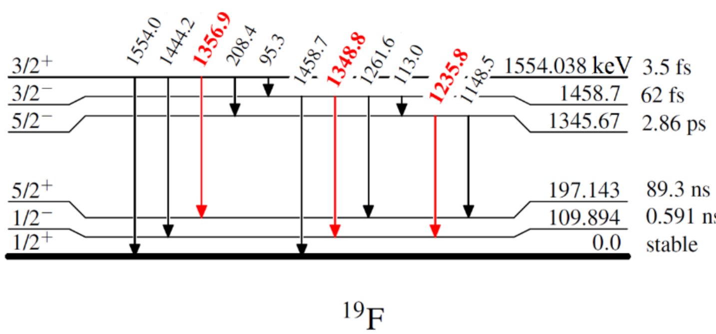
Ga-67 and Lu-177 are used in radiopharmaceuticals but do not emit gamma rays near 80 keV. Tl-201 is used in radiopharmaceuticals and emits an X-ray at 80.25 keV, but it also emits a strong gamma ray at 167.43 keV that is not observed in the spectrum above. Xe-133 emits a strong gamma ray at 81.00 keV, but it produces X-rays near 31 and 35 keV that do not match the spectrum above.

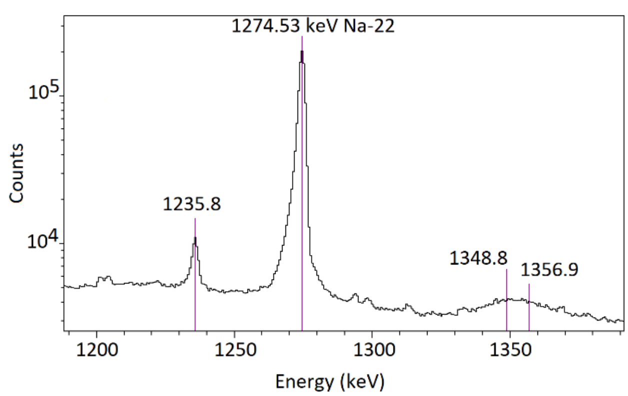
The metastable impurity Ho-166m (1200 year) generates a 184.4 keV gamma ray. This is similar to 185.7 keV from U-235, and so Ho-166m is sometimes used as a U-235 surrogate for testing purposes. However, Ho-166m also produces strong gamma rays at 810, 711, 280, 752 keV, and several other energies, which easily distinguish Ho-166m from U-235.

Question 10: Alpha particle interactions with fluorine (F) include 19F(α,n)22Na, 19F(α,α')19F*, and 19F(α,p)22Ne reactions. Some of the resulting signature peaks are Doppler-broadened, and other signature peaks are narrow.

Consider the decay diagram below, which illustrates 19F* excited states which de-excite to produce gamma rays at characteristic energies. The half-lives of the excited states are shown in the rightmost column. Assuming the excitation is due to alpha particle interaction, which gamma ray signature indicated in red is expected to show the LEAST amount of Doppler broadening (producing the narrowest peak)?

(A) 1235.8 keV
(B) 1348.8 keV
(C) 1356.9 keV





The spectrum [to the left] was collected from a Pu sample with fluorine impurities. The energies of the three 19F(α,α')19F* signatures are indicated, along with the signature energy of Na-22.

The 1235.8 keV gamma ray comes from decay of the 5/2- state, which has the longest half-life (2.86 ps = 2860 fs). This allows time for the recoiling 19F* time to come to rest before it decays, and Doppler broadening is negligible. The other two states have very short half-lives and so decay occurs while the nucleus is still moving rapidly after the collision with the α particle. As a result, the 1348.8 and 1356.9 keV peaks are strongly affected by Doppler broadening.

Half-life also affects natural line widths, with FWHM width $\Gamma = \hbar \ln 2 / T_{1/2}$ due to the Heisenberg uncertainty principle. The 3/2+ state has a natural width $\Gamma \approx 0.00013$ keV and the 3/2- and 5/2- states have even narrower natural widths. This is a much smaller effect than can be observed by any HPGe detector, and the broadening observed in this spectrum is almost entirely Doppler and not Heisenberg.