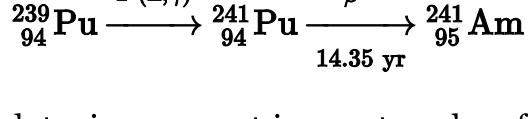
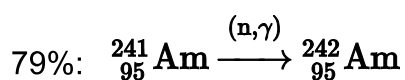


The capture of two neutrons by ${}^{239}\text{Pu}$ (a so-called (n,γ) reaction), followed by a β -decay, results in ${}^{241}\text{Am}$:



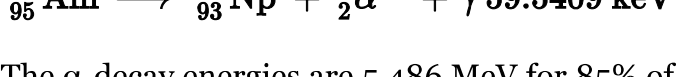
The plutonium present in spent nuclear fuel contains about 12% of ${}^{241}\text{Pu}$. Because it converts to ${}^{241}\text{Am}$, ${}^{241}\text{Pu}$ can be extracted and may be used to generate further ${}^{241}\text{Am}$.^[4] However, this process is rather slow: half of the original amount of ${}^{241}\text{Pu}$ decays to ${}^{241}\text{Am}$ after about 14 years, and the ${}^{241}\text{Am}$ amount reaches a maximum after 70 years.^[5]

The obtained ${}^{241}\text{Am}$ can be used for generating heavier americium isotopes by further neutron capture inside a nuclear reactor. In a light water reactor (LWR), 79% of neutron captures on ${}^{241}\text{Am}$ convert to ${}^{242}\text{Am}$ and 10% to its nuclear isomer ${}^{242\text{m}}\text{Am}$.^[6]



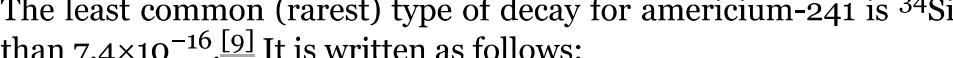
Decay

Americium-241 decays mainly via alpha decay, with a weak gamma ray byproduct. The α -decay is shown as follows:



The α -decay energies are 5.486 MeV for 85% of the time (the one which is widely accepted for standard α -decay energy), 5.443 MeV for 13% of the time, and 5.388 MeV for the remaining 2%.^[7] The γ -ray energy is 59.5409 keV for the most part, with little amounts of other energies such as 13.9 keV, 17.8 keV and 26.4 keV.^[8]

The second most common type of decay that americium-241 undergoes is spontaneous fission, with a branching ratio of 3.6×10^{-12} ^[9] and happening 1.2 times a second per gram of ${}^{241}\text{Am}$. It is written as such (the asterisk denotes an excited nucleus):



The least common (rarest) type of decay for americium-241 is ${}^{34}\text{Si}$ cluster decay, with a branching ratio of less than 7.4×10^{-16} .^[9] It is written as follows:



Applications

Ionization-type smoke detector

Americium-241 is the only synthetic isotope to have found its way into the household, where the most common type of smoke detector (the ionization-type) uses ${}^{241}\text{AmO}_2$ (americium-241 dioxide) as its source of ionizing radiation.^[10] This isotope is preferred over ${}^{226}\text{Ra}$ because it emits 5 times more alpha particles and relatively little harmful gamma radiation. With its half-life of 432.2 years, the americium in a smoke detector decreases and includes about 3% neptunium after 19 years, and about 5% after 32 years. The amount of americium in a typical new smoke detector is 0.29 micrograms (about one-third the weight of a grain of sand) with an activity of 1 microcurie (37 kBq). Some old industrial smoke detectors (notably from the Pyrotronics Corporation) can contain up to 80 μCi . The amount of ${}^{241}\text{Am}$ declines slowly as it decays into neptunium-237, a different transuranic element with a much longer half-life (about 2.14 million years). The radiated alpha particles pass through an ionization chamber, an air-filled space between two electrodes, which allows a small, constant

electric current to pass between the capacitor plates due to the radiation ionizing the air space between. Any smoke that enters the chamber blocks/absorbs some of the alpha particles from freely passing through and reduces the ionization and therefore causes a drop in the current. The alarm's circuitry detects this drop in the current and as a result, triggers the piezoelectric buzzer to sound. Compared to the alternative optical smoke detector, the ionization smoke detector is cheaper and can detect particles which are too small to produce significant light scattering. However, it is more prone to false alarms.^{[11][12][13][14]}

Manufacturing process

The process for making the americium used in the buttons on ionization-type smoke detectors begins with americium dioxide. The AmO₂ is thoroughly mixed with gold, shaped into a briquette, and fused by pressure and heat at over 1,470 °F (800 °C). A backing of silver and a front covering of gold (or an alloy of gold or palladium) are applied to the briquette and sealed by hot forging. The briquette is then processed through several stages of cold rolling to achieve the desired thickness and levels of radiation emission. The final thickness is about 0.008 inches (0.20 mm), with the gold cover representing about one percent of the thickness. The resulting foil strip, which is about 0.8 inches (20 mm) wide, is cut into sections 39 inches (1 m) long. The sources are punched out of the foil strip. Each disc, about 0.2 inches (5.1 mm) in diameter, is mounted in a metal holder, usually made of aluminium. The holder is the housing, which is the majority of what is seen on the button. The thin rim on the holder is rolled over to completely seal the cut edge around the disc.^[15]

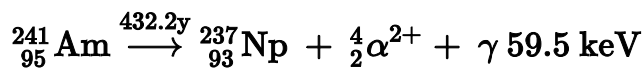
RTG (Radioisotope Thermoelectric Generator) power generation

As ²⁴¹Am has a *roughly* similar half-life to ²³⁸Pu (432.2 years vs. 87 years), it has been proposed as an active isotope of radioisotope thermoelectric generators, for use in spacecraft.^{[16][17]} Even though americium-241 produces less heat and electricity than plutonium-238 (the power yield is 114.7 mW/g for ²⁴¹Am vs. 390 mW/g for ²³⁸Pu)^[16] and its radiation poses a greater threat to humans owing to gamma and neutron emission, it has advantages for long duration missions with its significantly longer half-life. The European Space Agency is working on RTGs based on americium-241 for its space probes^[18] as a result of the global shortage of plutonium-238 and easy access to americium-241 in Europe from nuclear waste reprocessing.^{[19][20]}

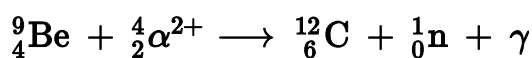
Its shielding requirements in an RTG are the second lowest of all possible isotopes: only ²³⁸Pu requires less. An advantage over ²³⁸Pu is that it is produced as nuclear waste and is nearly isotopically pure. Prototype designs of ²⁴¹Am RTGs expect 2–2.2 W_e/kg for 5–50 W_e RTGs design, putting ²⁴¹Am RTGs at parity with ²³⁸Pu RTGs within that power range.^[21]

Neutron source

Oxides of ²⁴¹Am pressed with beryllium can be very efficient neutron sources, since they emit alpha particles during radioactive decay:



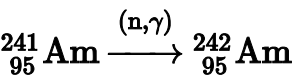
Here americium acts as the alpha source, and beryllium produces neutrons owing to its large cross-section for the (α,n) nuclear reaction:



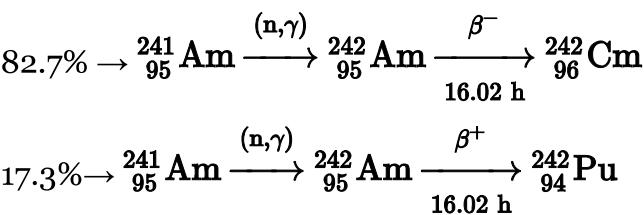
The most widespread use of ²⁴¹AmBe neutron sources is a neutron probe – a device used to measure the quantity of water present in soil, as well as moisture/density for quality control in highway construction. ²⁴¹Am neutron sources are also used in well logging applications, as well as in neutron radiography, tomography and other radiochemical investigations.^[22]

Production of other elements

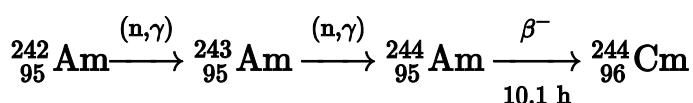
Americium-241 is sometimes used as a starting material for the production of other transuranic elements and transactinides – for example, neutron bombardment of ^{241}Am yields ^{242}Am :



From there, 82.7% of ^{242}Am decays to ^{242}Cm and 17.3% to ^{242}Pu :



In the nuclear reactor, ^{242}Am is also up-converted by neutron capture to ^{243}Am and ^{244}Am , which transforms by β -decay to ^{244}Cm :



Irradiation of ^{241}Am by ^{12}C or ^{22}Ne ions yields the isotopes ^{253}Es (einsteinium) or ^{263}Db (dubnium), respectively.^[23] Furthermore, the element berkelium (^{243}Bk isotope) had been first intentionally produced and identified by bombarding ^{241}Am with alpha particles, in 1949, by the same Berkeley group, using the same 60-inch cyclotron that had been used for many previous experiments. Similarly, nobelium was produced at the Joint Institute for Nuclear Research, Dubna, Russia, in 1965 in several reactions, one of which included irradiation of ^{243}Am with ^{15}N ions. Besides, one of the synthesis reactions for lawrencium, discovered by scientists at Berkeley and Dubna, included bombardment of ^{243}Am with ^{18}O .^[24]

Spectrometer

Americium-241 has been used as a portable source of both gamma rays and alpha particles for a number of medical and industrial uses. The 59.5409 keV gamma ray emissions from ^{241}Am in such sources can be used for indirect analysis of materials in radiography and X-ray fluorescence spectroscopy, as well as for quality control in fixed nuclear density gauges and nuclear densometers. For example, this isotope has been employed to gauge glass thickness to help create flat glass.^[3] Americium-241 is also suitable for calibration of gamma-ray spectrometers in the low-energy range, since its spectrum consists of nearly a single peak and negligible Compton continuum (at least three orders of magnitude lower intensity).^[25]

Medicine

Gamma rays from americium-241 have been used to provide passive diagnosis of thyroid function. This medical application is now obsolete. Americium-241's gamma rays can provide reasonable quality radiographs, with a 10-minute exposure time. ^{241}Am radiographs have only been taken experimentally due to the long exposure time which increases the effective dose to living tissue. Reducing exposure duration reduces the chance of ionization events causing damage to cells and DNA, and is a critical component in the "*time, distance, shielding*" maxim used in radiation protection.^[26]

Hazards

Americium-241 has the same general hazards as other americium isotopes: it is both extremely toxic and radioactive. Although α -particles can be stopped by a sheet of paper, there are serious health concerns for ingestion of α -emitters. Americium and its isotopes are also very chemically toxic as well, in the form of heavy-metal toxicity. As little as $0.03 \mu\text{Ci}$ (1,110 Bq) is the maximum permissible body burden for ^{241}Am .^[27]

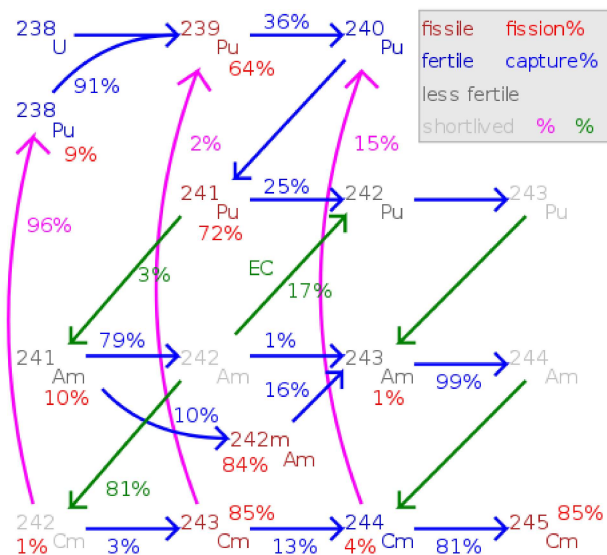


Chart displaying actinides and their decays and transmutations.

Americium-241 is an α -emitter with a weak γ -ray byproduct. Safely handling americium-241 requires knowing and following proper safety precautions, as without them it would be extremely dangerous. Its specific gamma dose constant is 3.14×10^{-1} mR/hr/mCi or 8.48×10^{-5} mSv/hr/MBq at 1 meter.^[28]

If consumed, americium-241 is excreted within a few days and only 0.05% is absorbed in the blood. From there, roughly 45% of it goes to the liver and 45% to the bones, and the remaining 10% is excreted. The uptake to the liver depends on the individual and increases with age. In the bones, americium is first deposited over cortical and trabecular surfaces and slowly redistributes over the bone with time. The biological half-life of ²⁴¹Am is 50 years in the bones and 20 years in the liver, whereas in the gonads (testicles and ovaries) it remains permanently; in all these organs, americium promotes formation of cancer cells as a result of its radioactivity.^[29]

Americium-241 often enters landfills from discarded smoke detectors. The rules associated with the disposal of smoke detectors are relaxed in most jurisdictions. In the U.S., the "Radioactive Boy Scout" David Hahn was able to concentrate americium-241 from smoke detectors after managing to buy a hundred of them at remainder prices and also stealing a few.^{[30][31][32][33]} There have been a few cases of exposure to americium-241, the worst case being that of Harold McCluskey, who at the age of 64 was exposed to 500 times the occupational standard for americium-241 as a result of an explosion in his lab. McCluskey died at the age of 75, not as a result of exposure, but of a heart disease which he had before the accident.^{[34][35]}



See also

Isotopes of americium

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