

Americium

An overview

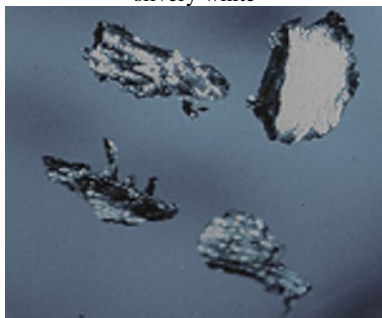
Contents

Articles

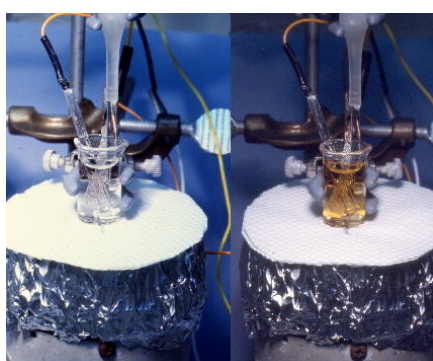
| | |
|--|-----------|
| Overview | 1 |
| Americium | 1 |
| Isotopes | 7 |
| Isotopes of americium | 7 |
| Americium-241 | 10 |
| Americium-242 | 11 |
| Americium-243 | 12 |
| Compounds | 14 |
| Americium dioxide | 14 |
| Americium(III) chloride | 15 |
| Discoverer | 17 |
| Glenn T. Seaborg | 17 |
| Miscellany | 26 |
| Actinides in the environment | 26 |
| References | |
| Article Sources and Contributors | 30 |
| Image Sources, Licenses and Contributors | 31 |
| Article Licenses | |
| License | 32 |

Overview

Americium

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|---|---|------|-----|-----|------|-------|--------------|---|----|-----|-----|------|-------|----------------|------|------|--|--|--|--|
| Americium | | | | | | | | | | | | | | | | | | | | |
| Appearance | | | | | | | | | | | | | | | | | | | | |
| silvery white | | | | | | | | | | | | | | | | | | | | |
|  | | | | | | | | | | | | | | | | | | | | |
| General properties | | | | | | | | | | | | | | | | | | | | |
| Name, symbol, number | americium, Am, 95 | | | | | | | | | | | | | | | | | | | |
| Pronunciation | /ˌæməˈrɪsiəm/ <i>AM-ə-RIS-ee-əm</i> | | | | | | | | | | | | | | | | | | | |
| Element category | actinide | | | | | | | | | | | | | | | | | | | |
| Group, period, block | n/a, 7, f | | | | | | | | | | | | | | | | | | | |
| Standard atomic weight | (243) g·mol ^{−1} | | | | | | | | | | | | | | | | | | | |
| Electron configuration | [Rn] 5f ⁷ 7s ² | | | | | | | | | | | | | | | | | | | |
| Electrons per shell | 2, 8, 18, 32, 25, 8, 2 (Image) | | | | | | | | | | | | | | | | | | | |
| Physical properties | | | | | | | | | | | | | | | | | | | | |
| Phase | solid | | | | | | | | | | | | | | | | | | | |
| Density (near r.t.) | 12 g·cm ^{−3} | | | | | | | | | | | | | | | | | | | |
| Melting point | 1449 K,1176 °C,2149 °F | | | | | | | | | | | | | | | | | | | |
| Boiling point | 2880 K,2607 °C,4725 °F | | | | | | | | | | | | | | | | | | | |
| Heat of fusion | 14.39 kJ·mol ^{−1} | | | | | | | | | | | | | | | | | | | |
| Specific heat capacity | (25 °C) 62.7 J·mol ^{−1} ·K ^{−1} | | | | | | | | | | | | | | | | | | | |
| Vapor pressure | | | | | | | | | | | | | | | | | | | | |
| <table><tr><td><i>P</i>/Pa</td><td>1</td><td>10</td><td>100</td><td>1 k</td><td>10 k</td><td>100 k</td></tr><tr><td>at <i>T</i>/K</td><td>1239</td><td>1356</td><td></td><td></td><td></td><td></td></tr></table> | | | | | | | <i>P</i> /Pa | 1 | 10 | 100 | 1 k | 10 k | 100 k | at <i>T</i> /K | 1239 | 1356 | | | | |
| <i>P</i> /Pa | 1 | 10 | 100 | 1 k | 10 k | 100 k | | | | | | | | | | | | | | |
| at <i>T</i> /K | 1239 | 1356 | | | | | | | | | | | | | | | | | | |
| Atomic properties | | | | | | | | | | | | | | | | | | | | |
| Oxidation states | 6, 5, 4, 3 , 2 (amphoteric oxide) | | | | | | | | | | | | | | | | | | | |

Chemical properties



Americium 3+ (left) and 4+ (right)

Americium oxidizes to AmO in air. Similarly, reaction with hydrogen results in AmH_2 where Am is divalent. However, the most common oxidation state of Am is +3, especially in solutions which are colored red. It is much harder to oxidize Am(III) to Am(IV) than it is to oxidize Pu(III) to Pu(IV).



World's first sample of americium (as the hydroxide)

Americium, unlike uranium, does not readily form a dioxide americyl core (AmO_2).^[3] This is because americium is very hard to oxidise above the +3 oxidation state when it is in an aqueous solution. In the environment, this americyl core could complex with carbonate as well as other oxygen moieties (OH^- , NO, NO_2 , and SO) to form charged complexes which tend to be readily mobile with low affinities to soil: $\text{AmO}_2(\text{OH})^+$, $\text{AmO}_2(\text{OH})_2^{2+}$, $\text{AmO}_2\text{CO}_3^+$, $\text{AmO}_2(\text{CO}_3^-)$ and $\text{AmO}_2(\text{CO}_3)_2$.

Examples of americium +4 compounds are $\text{Am}(\text{OH})_4$ and AmF_4 . All pentavalent and hexavalent americium compounds are complex salts such as KAmO_2F_2 , Li_3AmO_4 and Li_6AmO_6 , Ba_3AmO_6 , AmO_2F_2 . Hexavalent americium is a strong oxidizing agent and is reduced to AmO^{2+} in oxidation-reduction reactions.^[4]

Extraction

A large amount of work has been done on the solvent extraction of americium, as americium and other transuranic elements are responsible for much of the long-lived radiotoxicity of spent nuclear fuel. It is thought that by removal of the americium and curium that the used fuel will only need to be isolated from people and the environment for a shorter time than that required for the isolation of untreated used fuel.

One recent EU funded project on this topic was known by the codename "EUROPART". Within this project triazines and other compounds were studied as potential extraction agents.^{[5] [6] [7] [8] [9]}

Isotopes

Eighteen radioisotopes of americium have been characterized, with the most stable being ^{243}Am with a half-life of 7370 years, and ^{241}Am with a half-life of 432.2 years. All of the remaining radioactive isotopes have half-lives that are less than 51 hours, and the majority of these have half-lives that are less than 100 minutes. This element also has 8 meta states, with the most stable being $^{242\text{m}}\text{Am}$ ($t_{1/2}$ 141 years). The isotopes of americium range in atomic weight from 231.046 u (^{231}Am) to 249.078 u (^{249}Am).

History

Americium was first isolated by Glenn T. Seaborg, Leon O. Morgan, Ralph A. James, and Albert Ghiorso in late 1944 at the wartime Metallurgical Laboratory at the University of Chicago (now known as Argonne National Laboratory). The team created the isotope ^{241}Am by subjecting ^{239}Pu to successive neutron capture reactions in a nuclear reactor. This created ^{240}Pu and then ^{241}Pu which in turn decayed into ^{241}Am via beta decay.^[10]

Seaborg was granted a patent for "Element 95 and Method of Producing Said Element", whose unusually terse claim number 1 reads simply, "Element 95."^[11] The discovery of americium and curium was first announced informally on a children's quiz show in 1945.^[12]

Applications



Outside and inside view of an americium-based smoke detector

Americium can be produced in kilogram amounts and has some uses, mostly involving ^{241}Am since it is easiest to produce relatively pure samples of this isotope. Americium is the only synthetic element to have found its way into the household, where one common type of smoke detector uses ^{241}Am in the form of americium dioxide as its source of ionizing radiation.^[13] The amount of americium in a typical smoke detector when new is 1 microcurie or 0.28

microgram. This amount declines slowly as the americium decays into neptunium-237, a different transuranic element with a much longer half-life (about 2.14 million years). With its half-life of 432.2 years, the americium in a smoke detector includes about 3% neptunium after 19 years, and about 5% after 32 years.

^{241}Am has been used as a portable source of both gamma rays and alpha particles for a number of medical and industrial uses. Gamma ray emissions from ^{241}Am can be used for indirect analysis of materials radiography and for quality control in manufacturing fixed gauges. For example, the element has been employed to gauge glass thickness to help create flat glass. ^{241}Am gamma rays were also used to provide passive diagnosis of thyroid function. This medical application is obsolete. ^{241}Am can be combined with lighter elements (e.g., beryllium or lithium) to become a neutron emitter. This application has found uses in neutron radiography as well as a neutron emitting radioactive source. The most widespread use of $^{241}\text{AmBe}$ neutron sources is found in moisture/density gauges used for quality control in highway construction. ^{241}Am neutron sources are also critical for well logging applications. $^{242\text{m}}\text{Am}$ has been cited for use as an advanced nuclear rocket propulsion fuel.^{[14] [15]} This isotope is, however, extremely expensive to produce in usable quantities.

^{241}Am has recently been suggested for use as a denaturing agent in plutonium reactor fuel rods to render the fuel unusable for conversion to nuclear weapons.^[16]

Safety

Americium emits alpha and gamma radiation. The alpha decay of ^{241}Am is 3.5 times as active as that of radium. It is associated with 5.48 MeV alpha particles and 59 keV gamma emission, which can be a serious health hazard if ingested or inhaled.^[4]

See also

- Actinides in the environment

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- [11] Patent US3156523 (<http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=3156523>) (1964-11-10) Glenn T. Seaborg, *Element 95 and Method of Producing Said Element*.
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External links

- WebElements.com – Americium (<http://www.webelements.com/webelements/elements/text/Am/index.html>)
 - It's Elemental – Americium (<http://education.jlab.org/itselemental/ele095.html>)
 - ATSDR – Public Health Statement: Americium (<http://www.atsdr.cdc.gov/toxprofiles/phs156.html>)
 - - World Nuclear Association (<http://world-nuclear.org/info/inf57.html>)
-

Isotopes

Isotopes of americium

| Actinides | | | | Half-life | Fission products | | | |
|--------------------|---------------------|---------------------|---------------------|--------------------|---|-----------------------|-----------------------|------------------|
| ²⁴⁴ Cm | ²⁴¹ Pu f | ²⁵⁰ Cf | ²⁴³ Cm f | 10–30 y | ¹³⁷ Cs | ⁹⁰ Sr | ⁸⁵ Kr | |
| ²³² U f | | ²³⁸ Pu | f is for fissile | 69–90 y | | | ¹⁵¹ Sm nc□ | |
| 4n | ²⁴⁹ Cf f | ²⁴² Am f | | 141–351 | No fission product has half-life 10 ² to 2×10 ⁵ years | | | |
| | ²⁴¹ Am | | ²⁵¹ Cf f | 431–898 | | | | |
| ²⁴⁰ Pu | ²²⁹ Th | ²⁴⁶ Cm | ²⁴³ Am | 5–7 ky | | | | |
| 4n | ²⁴⁵ Cm f | ²⁵⁰ Cm | ²³⁹ Pu f | 8–24 ky | | | | |
| | ²³³ U f | ²³⁰ Th | ²³¹ Pa | 32–160 | | | | |
| | 4n+1 | ²³⁴ U | 4n+3 | 211–290 | ⁹⁹ Tc | | ¹²⁶ Sn | ⁷⁹ Se |
| ²⁴⁸ Cm | | ²⁴² Pu | | 340–373 | Long-lived fission products | | | |
| | ²³⁷ Np | 4n+2 | | 1–2 my | ⁹³ Zr | ¹³⁵ Cs nc□ | | |
| ²³⁶ U | 4n+1 | | ²⁴⁷ Cm f | 6–23 | | ¹⁰⁷ Pd | ¹²⁹ I | |
| ²⁴⁴ Pu | | | | 80 my | >7% | >5% | >1% | >.1% |
| ²³² Th | | | ²³⁸ U | ²³⁵ U f | 0.7–12by | fission product yield | | |

Americium (Am) has no stable isotopes. A standard atomic mass cannot be given.

19 radioisotopes of americium have been characterized, with the most stable being ²⁴³Am with a half-life of 7370 years, and ²⁴¹Am with a half-life of 432.7 years. All of the remaining radioactive isotopes have half-lives that are less than 51 hours, and the majority of these have half-lives that are less than 100 minutes. This element also has 8 meta states, with the most stable being ^{242m}Am (t_{1/2} 141 years). The isotopes of americium range in atomic weight from 231.046 u (²³¹Am) to 249.078 u (²⁴⁹Am).



Table

| nuclide symbol | Z(p) | N(n) | isotopic mass (u) | half-life | nuclear spin |
|--------------------|----------------|------|-------------------|--------------|-----------------|
| | | | excitation energy | | |
| ²³¹ Am | 95 | 136 | 231.04556(32)# | 30# s | |
| ²³² Am | 95 | 137 | 232.04659(32)# | 79(2) s | |
| ²³³ Am | 95 | 138 | 233.04635(11)# | 3.2(8) min | |
| ²³⁴ Am | 95 | 139 | 234.04781(22)# | 2.32(8) min | |
| ²³⁵ Am | 95 | 140 | 235.04795(13)# | 9.9(5) min | 5/2-# |
| ²³⁶ Am | 95 | 141 | 236.04958(11)# | 3.6(1) min | |
| ²³⁷ Am | 95 | 142 | 237.05000(6)# | 73.0(10) min | 5/2(-) |
| ²³⁸ Am | 95 | 143 | 238.05198(5) | 98(2) min | 1+ |
| ^{238m} Am | 2500(200)# keV | | | 35(10) μs | |
| ²³⁹ Am | 95 | 144 | 239.0530245(26) | 11.9(1) h | (5/2)- |
| ^{239m} Am | 2500(200) keV | | | 163(12) ns | (7/2+) |
| ²⁴⁰ Am | 95 | 145 | 240.055300(15) | 50.8(3) h | (3-) |
| ²⁴¹ Am | 95 | 146 | 241.0568291(20) | 432.2(7) a | 5/2- |
| ^{241m} Am | 2200(100) keV | | | 1.2(3) μs | |
| ²⁴² Am | 95 | 147 | 242.0595492(20) | 16.02(2) h | 1- |

| | | | | | |
|---------------------|--------------|-----|-----------------|--------------|---------|
| ^{242m1} Am | 48.60(5) keV | | | 141(2) a | 5- |
| ^{242m2} Am | 2200(80) keV | | | 14.0(10) ms | (2+,3-) |
| ²⁴³ Am | 95 | 148 | 243.0613811(25) | 7.37(4)E+3 a | 5/2- |
| ²⁴⁴ Am | 95 | 149 | 244.0642848(22) | 10.1(1) h | (6-)# |
| ^{244m} Am | 86.1(10) keV | | | 26(1) min | 1+ |
| ²⁴⁵ Am | 95 | 150 | 245.066452(4) | 2.05(1) h | (5/2)+ |
| ²⁴⁶ Am | 95 | 151 | 246.069775(20) | 39(3) min | (7-) |
| ^{246m1} Am | 30(10) keV | | | 25.0(2) min | 2(-) |
| ^{246m2} Am | ~2000 keV | | | 73(10) μs | |
| ²⁴⁷ Am | 95 | 152 | 247.07209(11)# | 23.0(13) min | (5/2)# |
| ²⁴⁸ Am | 95 | 153 | 248.07575(22)# | 3# min | |
| ²⁴⁹ Am | 95 | 154 | 249.07848(32)# | 1# min | |

Notes

- Values marked # are not purely derived from experimental data, but at least partly from systematic trends. Spins with weak assignment arguments are enclosed in parentheses - ().
- Uncertainties are given in concise form in parentheses after the corresponding last digits. Uncertainty values denote one standard deviation, except isotopic composition and standard atomic mass from IUPAC which use expanded uncertainties.

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Americium-241

Americium-241 is the most prevalent isotope of Americium in nuclear waste.^[1] It's the americium isotope used in smoke detectors based on ionization chambers. It's a potential fuel for long-lifetime radioisotope thermoelectric generators.

| Parameter | Value |
|----------------------|---------------|
| Atomic mass | 241.056823 u |
| Mass excess | 52930 keV |
| Beta decay energy | -767 keV |
| Spin | 5/2- |
| Half life | 432.2 years |
| Spontaneous fissions | 1200 per kg/s |
| Decay heat | 114 watts/kg |

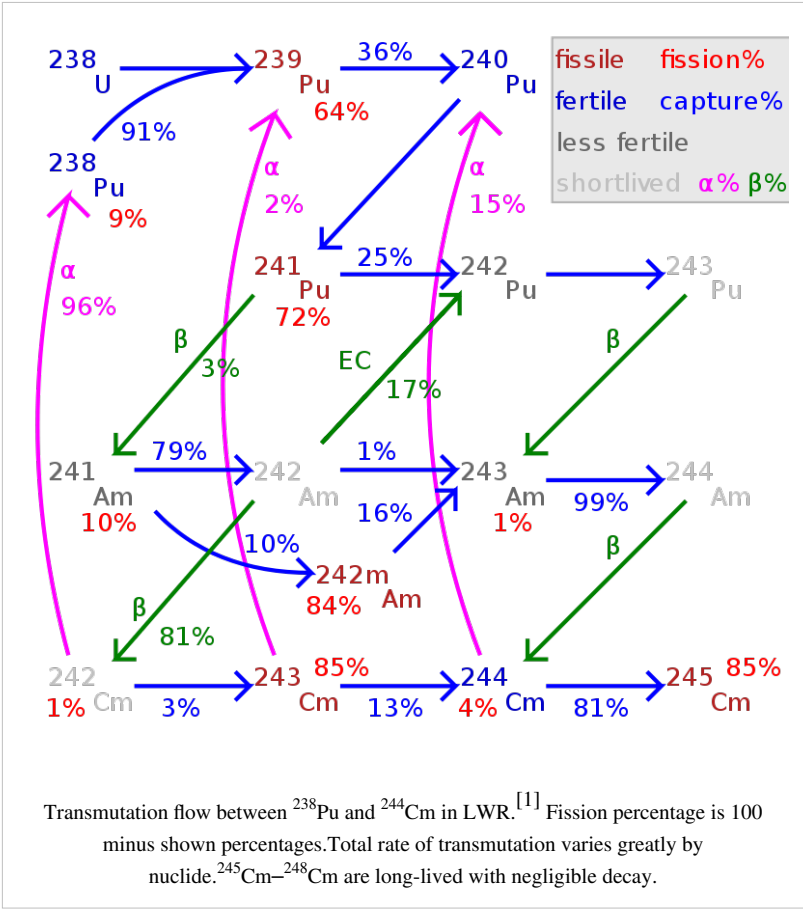
Possible parent nuclides: beta from Pu-241, electron capture from Cm-241, alpha from Bk-245

Americium-241 decays by alpha emission, with a by-product of gamma rays. Its presence in plutonium is determined by the original concentration of plutonium-241 and the sample age. Because of the low penetration of alpha radiation, Americium-241 only poses a health risk when ingested or inhaled. Older samples of plutonium containing plutonium-241 contain a buildup of Am-241. A chemical removal of americium from reworked plutonium, e.g. during reworking of plutonium pits, may be required.

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-

Americium-242



^{242m}Am decay modes (halflife: 141 years)

| Probability | Decay mode | Decay energy | Decay product |
|---------------------------------|---------------------|--------------|-------------------|
| 99.54% | isomeric transition | 0.05 MeV | ²⁴² Am |
| 0.46% | alpha decay | 5.64 MeV | ²³⁸ Np |
| (1.5±0.6)×10 ⁻¹⁰ [2] | spontaneous fission | ~200 MeV | fission products |

Americium-242m is one of the isotopes of americium, with 95 protons and electrons and 147 neutrons and a mass of 242.0595492 g/mol. It is one of the rare cases, like tantalum-180m, where a higher-energy nuclear isomer is more stable than the lower-energy one, **Americium-242**.^[3]

^{242m}Am is fissile (because it has an odd number of neutrons) and has a low critical mass, comparable to that of plutonium-239.^[4] It has a very high cross section for fission, and if in a nuclear reactor is destroyed relatively quickly. Another report claims that ^{242m}Am has a much lower critical mass, can sustain a chain reaction even as a thin film, and could be used for a novel type of nuclear rocket.^[5]

²⁴²Am decay modes (halflife: 16 hours)

| Probability | Decay mode | Decay energy | Decay product |
|-------------|------------------|--------------|-------------------|
| 82.70% | beta decay | 0.665 MeV | ²⁴² Cm |
| 17.30% | electron capture | 0.751 MeV | ²⁴² Pu |

See also

- Americium
- Isotopes of americium

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[5] Extremely Efficient Nuclear Fuel Could Take Man To Mars In Just Two Weeks (<http://www.sciencedaily.com/releases/2001/01/010103073253.htm>)

Americium-243

| Actinides | | | | Half-life | Fission products | | | |
|--------------------|---------------------|---------------------|---------------------|-----------|---|----------------------|----------------------|------------------|
| ²⁴⁴ Cm | ²⁴¹ Pu f | ²⁵⁰ Cf | ²⁴³ Cm f | 10–30 y | ¹³⁷ Cs | ⁹⁰ Sr | ⁸⁵ Kr | |
| ²³² U f | | ²³⁸ Pu | f is for fissile | 69–90 y | | | ¹⁵¹ Sm nc | |
| 4n | ²⁴⁹ Cf f | ²⁴² Am f | | 141–351 | No fission product has half-life 10 ² to 2×10 ⁵ years | | | |
| | ²⁴¹ Am | | ²⁵¹ Cf f | 431–898 | | | | |
| ²⁴⁰ Pu | ²²⁹ Th | ²⁴⁶ Cm | ²⁴³ Am | 5–7 ky | | | | |
| 4n | ²⁴⁵ Cm f | ²⁵⁰ Cm | ²³⁹ Pu f | 8–24 ky | | | | |
| | ²³³ U f | ²³⁰ Th | ²³¹ Pa | 32–160 | | | | |
| | 4n+1 | ²³⁴ U | 4n+3 | 211–290 | ⁹⁹ Tc | | ¹²⁶ Sn | ⁷⁹ Se |
| ²⁴⁸ Cm | | ²⁴² Pu | | 340–373 | Long-lived fission products | | | |
| | ²³⁷ Np | 4n+2 | | 1–2 my | ⁹³ Zr | ¹³⁵ Cs nc | | |
| ²³⁶ U | 4n+1 | | ²⁴⁷ Cm f | 6–23 | | ¹⁰⁷ Pd | ¹²⁹ I | |
| ²⁴⁴ Pu | | | | 80 my | >7% | >5% | >1% | >1% |
| ²³² Th | | ²³⁸ U | ²³⁵ U f | 0.7–12by | fission product yield | | | |

Americium-243 is a radioactive isotope of americium having 95 electrons and protons and 148 neutrons and has a mass of 243.06138 g/mol.

It has a half-life of 7370 years, the longest lasting of all americium isotopes, however, it is still not found in nature. It is formed in the nuclear fuel cycle by neutron capture on plutonium-242 followed by beta decay.^[1] Production increases exponentially with increasing burnup as a total of 5 neutron captures on uranium-238 are required.

It either decays by emitting an alpha particle (the decay energy is 5.27MeV)^[2] to turn into neptunium-239, which then quickly decays to plutonium-239, or infrequently, by spontaneous fission.^[3]

Americium-243 is a hazardous substance, because it can cause cancer. Neptunium-239, which is formed from Americium-243, emits dangerous gamma rays, making Americium-243 the most dangerous isotope of Americium.^[4]

See also

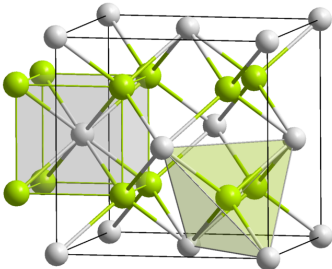
- Americium
- Americium-241
- Isotopes of americium

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Compounds

Americium dioxide

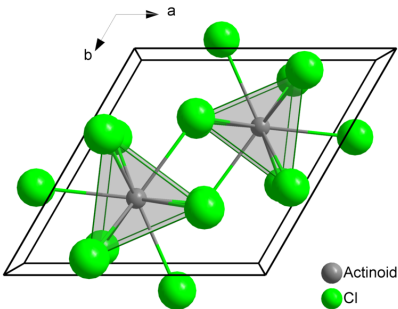
| Americium dioxide | |
|--|-------------------------------|
|  | |
| Identifiers | |
| CAS number | 12005-67-3 ^[1] |
| Properties | |
| Molecular formula | AmO ₂ |
| Molar mass | 275.06 g/mol |
| Appearance | black / gold streak |
| Structure | |
| Crystal structure | Fluorite (cubic), <i>cF12</i> |
| Space group | Fm3m, No. 225 |
| Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa) | |
| Infobox references | |

Americium dioxide (AmO₂) is a compound of americium. It is used as a source of alpha particles, particularly in ionisation-type smoke detectors. In the solid state AmO₂ adopts the fluorite, CaF₂ structure.^[2]

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Americium(III) chloride

| Americium(III) chloride | |
|--|---|
|  | |
| Identifiers | |
| CAS number | 13464-46-5 ^[1] |
| Properties | |
| Molecular formula | AmCl ₃ |
| Molar mass | 349.419 g/mol |
| Appearance | pink hexagonal crystals |
| Density | 5.87 g/cm ³ ^[2] |
| Melting point | 715 °C ^[3] |
| Boiling point | 850 °C ^[2] |
| Structure | |
| Crystal structure | hexagonal (UCl ₃ type), hP8 |
| Space group | P6 ₃ /m, No. 176 |
| Coordination geometry | Tricapped trigonal prismatic (nine-coordinate) |
| Related compounds | |
| Other anions | Americium(II) chloride Americium(IV) oxide |
| Other cations | Plutonium(III) chloride Europium(III) chloride Samarium(III) chloride |
| Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa) | |
| Infobox references | |

Americium(III) chloride or **americium trichloride** is the chemical compound composed of americium and chlorine with the formula AmCl₃. It forms pink hexagonal crystals. In the solid state each americium atom has nine chlorine atoms as near neighbours, at approximately the same distance, in a tricapped trigonal prismatic configuration. ^[4] ^[5]

The hexahydrate has a monocline crystal structure with: a = 970,2 pm, b = 656,7 pm and c = 800,9 pm; β = 93° 37'; space group: *P2₁/n*. ^[6]

Reactions

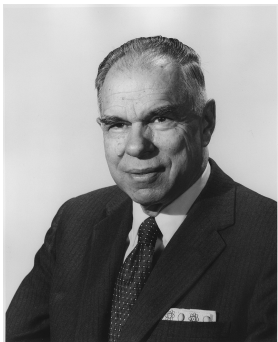
An americium(III) chloride electrorefining method has been investigated to separate mixtures of lanthanides, since the standard Gibbs free energy of formation of americium(III) chloride is much different than the rest of the lanthanide chlorides.^[7] This can be used to remove americium from plutonium by melting the crude mixture together with salts such as sodium chloride.^[8]

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- [2] "Chemistry: Periodic Table: americium: compound data (americium (III) chloride)" (http://www.webelements.com/compounds/americium/americium_trichloride.html). WebElements. . Retrieved 2008-06-24.
- [3] Perry, Dale L.; Phillips, Sidney L. (1995), *Handbook of Inorganic Compounds* (<http://books.google.com/?id=0fT4wfhF1AsC&pg=PA15>), CRC Press, pp. 15, ISBN 0-84938671-3, , retrieved 2008-06-25
- [4] L. B. Asprey, T. K. Keenan, F. H. Kruse: "Crystal Structures of the Trifluorides, Trichlorides, Tribromides, and Triiodides of Americium and Curium", *Inorg. Chem.* **1965**, 4 (7), 985–986; doi:10.1021/ic50029a013.
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- [7] Nuclear Energy Agency (2000), written at Avignon, France, *Proceedings of the Workshop on Pyrochemical Separations* (<http://books.google.com/?id=Gv7ohTjfG0UC&pg=PA277&dq=Americium+chloride>), OECD Publishing, pp. 276–277, ISBN 9-26418443-0, , retrieved 2008-06-24
- [8] *Plutonium Processing In The Nuclear Weapons Complex* (<http://books.google.com/?id=0fc3lpCtUM4C&pg=PA21&dq=Americium+chloride>), Diane Publishing, 1992, pp. 21, ISBN 1-56806568-X, , retrieved 2008-06-24

Discoverer

Glenn T. Seaborg

| Glenn T. Seaborg | |
|---|---|
|  | |
| Born | April 19, 1912 Ishpeming, Michigan, USA |
| Died | February 25, 1999 (aged 86) Lafayette, California, USA |
| Nationality | United States |
| Fields | Nuclear chemistry |
| Institutions | University of California, Berkeley Manhattan Project Atomic Energy Commission |
| Alma mater | UC Los Angeles UC Berkeley |
| Doctoral advisor | George Ernest Gibson Gilbert Newton Lewis |
| Doctoral students | Ralph Arthur James Joseph William Kennedy Kenneth Ross Mackenzie Arthur Wall |
| Known for | Discovery of ten transuranium elements |
| Notable awards | Nobel Prize in Chemistry (1951) Perkin Medal (1957) Priestley Medal (1979) Franklin Medal (1963) |

Glenn Theodore Seaborg (Swedish: *Glenn Teodor Sjöberg*; April 19, 1912 – February 25, 1999) was an American scientist who won the 1951 Nobel Prize in Chemistry for "discoveries in the chemistry of the transuranium elements",^[1] contributed to the discovery and isolation of ten elements, and developed the *actinide concept*, which led to the current arrangement of the actinoid series in the periodic table of the elements. He spent most of his career as an educator and research scientist at the University of California, Berkeley where he became the second Chancellor in its history and served as a University Professor.^[2] Seaborg advised ten presidents from Truman to Clinton on nuclear policy and was the chairman of the United States Atomic Energy Commission from 1961 to 1971

where he pushed for commercial nuclear energy and peaceful applications of nuclear science. Throughout his career, Seaborg worked for arms control. He was signator to the Franck Report and contributed to the achievement of the Limited Test Ban Treaty, the Nuclear Non-Proliferation Treaty, and the Comprehensive Test Ban Treaty.^[3] Seaborg was a well-known advocate of science education and federal funding for pure research. He was a key contributor to the report "A Nation at Risk" as a member of President Reagan's National Commission on Excellence in Education and was the principal author of the Seaborg Report on academic science issued in the closing days of the Eisenhower administration.^[4]

Seaborg was the principal or co-discoverer of ten elements: plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium and element 106, which was named seaborgium in his honor while he was still living. He also developed more than 100 atomic isotopes, and is credited with important contributions to the chemistry of plutonium, originally as part of the Manhattan Project where he developed the extraction process used to isolate the plutonium fuel for the second atomic bomb. Early in his career, Seaborg was a pioneer in nuclear medicine and developed numerous isotopes of elements with important applications in the diagnosis and treatment of diseases, most notably iodine-131, which is used in the treatment of thyroid disease. In addition to his theoretical work in the development of the actinide concept which placed the actinide series beneath the lanthanide series on the periodic table, Seaborg proposed the placement of super-heavy elements in the transactinide and superactinide series.^[5] After sharing the 1951 Nobel Prize in Chemistry with Edwin McMillan, he received approximately 50 honorary doctorates and numerous other awards and honors. The list of things named after Seaborg ranges from his atomic element to an asteroid. Seaborg was a prolific author, penning more than 50 books and 500 journal articles, often in collaboration with others. He received so many awards and honors that he was once listed in the Guinness Book of World Records as the person with the longest entry in *Who's Who in America*.

Biography

Of Swedish ancestry, Seaborg was born in Ishpeming, Michigan, the son of Herman Theodore (Ted) and Selma Olivia Erickson Seaborg. He had one sister, Jeanette. When Glenn Seaborg was a boy, the family moved to the Seaborg Home in a subdivision called Home Gardens, that was later annexed to the City of South Gate, California, a suburb of Los Angeles.

He kept a daily journal from 1927 until he suffered a stroke in 1998. As a youth, Seaborg was both a devoted sports fan and an avid movie buff. His mother encouraged him to become a book-keeper as she felt his literary interests were impractical. He did not take an interest in science until his junior year when he was inspired by Dwight Logan Reid, a chemistry and physics teacher at David Starr Jordan High School in Watts.^[6]

He graduated from Jordan in 1929 at the top of his class and received a bachelor's degree in chemistry at the University of California, Los Angeles in 1934. While at UCLA, he was invited by his German professor to meet Albert Einstein, an experience that had a profound impact on Seaborg and served as a model of graciousness for his encounters with aspiring students in later years. Seaborg worked his way through school as a stevedore (longshoreman), fruit packer and laboratory assistant.^[7]

Graduate work

Seaborg took his Ph.D. in chemistry at the University of California, Berkeley, in 1937 with a doctoral thesis on the inelastic scattering of neutrons in which he coined the term "nuclear spallation". He was a member of the professional chemistry fraternity Alpha Chi Sigma. As a graduate student in the 1930s Seaborg performed wet chemistry research for his advisor Gilbert Newton Lewis and published three papers with him on the theory of acids and bases. Seaborg then studied thoroughly the text *Applied Radiochemistry* by Otto Hahn, of the Kaiser Wilhelm Institute for Chemistry in Berlin and it had a major impact on his developing interests as a research scientist. For several years, Seaborg conducted important research in artificial radioactivity using the Lawrence cyclotron at UC Berkeley.^[8] He was excited to learn from others that nuclear fission was possible—but also chagrined, as his own

research might have led him to the same discovery.^[9]

Seaborg also became expert in dealing with noted Berkeley physicist Robert Oppenheimer. Oppenheimer had a daunting reputation, and often answered a junior man's question before it had even been stated. Often the question answered was more profound than the one asked, but of little practical help. Seaborg learned to state his questions to Oppenheimer quickly and succinctly.^[10]

Career

Pioneering work in nuclear chemistry

Seaborg remained at the University of California, Berkeley for post-doctoral research. He followed Frederick Soddy's work investigating isotopes and contributed to the discovery of more than 100 isotopes of elements. Using one of Lawrence's advanced cyclotrons, John Livingood, Fred Fairbrother, and Seaborg created a new isotope of iron, iron-59 (Fe-59) in 1937. Iron-59 was useful in the studies of the hemoglobin in human blood. In 1938, Livingood and Seaborg collaborated (as they did for five years) to create an important isotope of iodine, iodine-131 (I-131) which is still used to treat thyroid disease.^[11] (Many years later, it was credited with prolonging the life of Seaborg's mother.) As a result of these and other contributions, Seaborg is regarded as a pioneer in nuclear medicine and is one of its most prolific discoverers of isotopes.^[12]

In 1939 he became an instructor in chemistry at UC Berkeley, was promoted to assistant professor in 1941 and professor in 1945.^[13]

UC Berkeley physicist Edwin McMillan had led a team that discovered element 93, neptunium in 1940. However in November 1940, McMillan was persuaded to leave Berkeley temporarily to assist with urgent research needed to advance radar technology. Since Seaborg and his colleagues had perfected McMillan's oxidation-reduction technique for isolating neptunium, he asked McMillan for permission to continue the research and search for element 94. McMillan agreed to the collaboration.^[14] Seaborg first reported alpha decay proportionate to only a fraction of the element 93 under observation. The first hypothesis for this alpha particle accumulation was contamination by uranium, which produces alpha-decay particles. However, an analysis of alpha-decay particles ruled out the hypothesis. Seaborg then postulated that a distinct alpha-producing element was being formed from element 93. In February 1941, Seaborg and his collaborators produced plutonium-239 through the bombardment of uranium. This experimental achievement changed the course of human history in ways more profound than they could have ever imagined: the production of plutonium-239 was successful. In their experiments bombarding uranium with deuterons, they observed the creation of neptunium, element 93. But it then underwent beta-decay, forming a new element, plutonium, with 94 protons. Plutonium is fairly stable, but undergoes alpha-decay, which explained the presence of alpha particles coming from neptunium.^[15] Thus, on March 28, 1941, Dr. Seaborg, physicist Emilio Segrè and Berkeley chemist Joseph W. Kennedy were able to show that plutonium (then known only as element 94²³⁹) underwent fission with slow neutrons, an important distinction that was crucial to the decisions made in directing Manhattan Project research. Room 307 of Gilman Hall on the UC Berkeley campus, where Seaborg did his work, has since been declared a U.S. National Historic Landmark.

In the same year in which he produced plutonium, 1941, he also discovered that the isotope U^{235} undergoes fission under appropriate conditions. He therefore contributed to the science enabling two different approaches to the development of nuclear weapons.

In addition to plutonium, he is credited as a lead discoverer of americium, curium, and berkelium, and as a co-discoverer of californium, einsteinium, fermium, mendelevium, nobelium and seaborgium. He shared the Nobel Prize in Chemistry in 1951 with Edwin McMillan for "their discoveries in the chemistry of the first transuranium elements." He obtained patents on americium and curium, which were developed in 1944 in Chicago at the wartime metallurgical laboratory during the Manhattan project. His research contributions to all of the other elements were conducted at the University of California, Berkeley.

Scientific contributions during the Manhattan Project

On April 19, 1942, Seaborg reached Chicago, and joined the chemistry group at the Metallurgical Laboratory of the Manhattan Project at the University of Chicago, where Enrico Fermi and his group would later convert U^{238} to plutonium in the world's first controlled nuclear chain reaction using a chain-reacting pile. Seaborg's role was to figure out how to extract the tiny bit of plutonium from the mass of uranium. Plutonium-239 was isolated in visible amounts using a transmutation reaction on August 20, 1942 and weighed on September 10, 1942 in Seaborg's Chicago laboratory. He was responsible for the multi-stage chemical process that separated, concentrated and isolated plutonium. This process was further developed at the Clinton Engineering Works in Oak Ridge, Tennessee and then entered full-scale production at the Hanford Engineer Works, in Richland, Washington.^[16]

Seaborg's theoretical development of the actinide concept resulted in a redrawing of the Periodic Table of the Elements into its current configuration with the actinide series appearing below the lanthanide series. Seaborg developed the chemical elements americium and curium while in Chicago. He managed to secure patents for both elements. His patent on curium never proved commercially viable because of the element's short half-life. Americium is commonly used in household smoke detectors, however, and thus provided a good source of royalty income to Seaborg in later years. Prior to the test of the first nuclear weapon, Seaborg joined with several other leading scientists in a written statement known as the Franck Report (secret at the time but since published) calling on President Truman to conduct a public demonstration of the atomic bomb witnessed by the Japanese rather than engaging in a surprise attack. Truman instead proceeded to drop two bombs, credited by most observers at the time with ending the war, a uranium bomb on Hiroshima and a plutonium bomb on Nagasaki.^[17]

Professor and Chancellor at the University of California, Berkeley

After the conclusion of World War II and the Manhattan Project, Seaborg was eager to return to academic life and university research free from the restrictions of wartime secrecy. In 1946, he added to his responsibilities as a professor by heading the nuclear chemistry research at the Lawrence Radiation Laboratory operated by the University of California on behalf of the United States Atomic Energy Commission. Seaborg was named one of the "Ten Outstanding Young Men in America" by the U.S. Junior Chamber of Commerce in 1947 (along with Richard Nixon and others). Seaborg was elected to the National Academy of Sciences in 1948. From 1954 to 1961 he served as associate director of the radiation laboratory. He was appointed by President Truman to serve as a member of the General Advisory Committee of the Atomic Energy Commission, an assignment he retained until 1960.

Seaborg served as chancellor at University of California, Berkeley from 1958 to 1961. His term as Chancellor came at a time of considerable controversy during the time of the free speech movement. In October 1958, he announced that the University had relaxed its prior prohibitions on political activity on a test basis.^[18] Seaborg served on the Faculty Athletic Committee for several years and is the co-author of a book concerning the Pacific Coast Conference scandal and the founding of the Pac-10 (formerly Pac-8), in which he played a role. Seaborg served on the President's Science Advisory Commission during the Eisenhower administration, which produced the report "Scientific Progress, the Universities, and the Federal Government," also known as the "Seaborg Report," in November 1960. The Seaborg Report is credited with influencing the federal policy towards academic science for the next eight years. In 1959, he helped found the Berkeley Space Sciences Laboratory with UC president Clark Kerr.

Chairman of the Atomic Energy Commission

After appointment by President John F. Kennedy and confirmation by the United States Senate, Seaborg was chairman of the United States Atomic Energy Commission (AEC) from 1961 to 1971. His pending appointment by President Kennedy was nearly derailed in late 1960 when members of the Kennedy transition team learned that Seaborg had been listed in a U.S. News and World Report article as a member of "Nixon's Brain Trust." Seaborg said that as a lifetime Democrat he was baffled when the article appeared associating him with Vice President Nixon,

whom he considered a casual acquaintance.

While chairman of the AEC, Seaborg participated on the negotiating team for the Limited Test Ban Treaty (LTBT). Seaborg considered his contributions to the achievement of the LTBT as his greatest accomplishment. Despite strict rules from the Soviets about photography at the signing ceremony, Seaborg sneaked a tiny camera past the Soviet guards to take a close-up photograph of Soviet Premier Khrushchev as he signed the treaty.

Seaborg enjoyed a close relationship with President Lyndon Johnson and influenced the administration to pursue the Nuclear Non-Proliferation Treaty.

Seaborg was called to the White House in the first week of the Nixon Administration in January 1969 to advise President Richard Nixon on his first diplomatic crisis involving the Soviets and nuclear testing. Seaborg clashed with Nixon presidential adviser John Ehrlichman over the treatment of a Jewish scientist whom the Nixon administration suspected of leaking nuclear secrets to Israel.

Seaborg published several books and journal articles during his tenure at the Atomic Energy Commission. His predictions concerning development of stable super-heavy elements are considered among his most important theoretical contributions.^[19] Seaborg theorized the transactinide series and the superactinide series of undiscovered synthetic elements. While most of these theoretical future elements have extremely short half-lives and thus no expected practical applications, Seaborg theorized an island of stability for isotopes of certain elements.^[20]

When Seaborg resigned as chairman of the Atomic Energy Commission in 1971, he had served longer than any other Kennedy appointee.

Return to California

Following his service as Chairman of the Atomic Energy Commission, Seaborg returned to UC Berkeley where he was awarded the position of University Professor. At the time, there had been fewer University Professors at UC Berkeley than Nobel prize winners. He also served as Chairman of the Lawrence Hall of Science. Seaborg served as President of the American Association for the Advancement of Science in 1972 and as President of the American Chemical Society in 1976. In 1976, when the Swedish king visited the United States, Seaborg played a major role in welcoming the Swedish Royal Family.

In 1980, he transmuted several thousand atoms of bismuth into gold at the Lawrence Berkeley Laboratory.^[21] His experimental technique, using nuclear physics, was able to remove protons and neutrons from the bismuth atoms. Seaborg's technique would have been far too expensive to enable routine manufacturing of gold, but his work is the closest to the mythical Philosopher's Stone.

In 1983, President Ronald Reagan appointed Seaborg to serve on the National Commission on Excellence in Education. Upon seeing the final draft report, Seaborg is credited with making comments that it was far too weak and did not communicate the urgency of the current crisis. He compared the crisis in education to the arms race, and stated that we are "a nation at risk." These comments led to a new introduction to the report and gave the report the famous title which focused national attention on education as an issue germane to the federal government.



President Kennedy and his Atomic Energy Commission Chairman, Glenn Seaborg.



Glenn T. Seaborg with Vice President Al Gore in the White House during a visit of the 1993 Science Talent Search (STS) finalists on March 4, 1993.

Seaborg lived most of his later life in Lafayette, California, where he devoted himself to editing and publishing the journals that documented both his early life and later career. He rallied a group of scientists who criticized the science curriculum in the State of California which he viewed as far too socially oriented and not nearly focused enough on hard science. California Governor Pete Wilson appointed Seaborg to head a committee that proposed sweeping changes to California's science curriculum despite outcries from labor organizations and others.

On August 24, 1998, while in Boston to attend a meeting by the American Chemical Society, Seaborg suffered a stroke, which led to his death six months later on February 25, 1999 at his home in Lafayette.

During his lifetime, Seaborg is said to have been the author or co-author of more than 50 books and 500 scientific journal articles, many of them brief reports on fast-breaking discoveries in nuclear science while other subjects, most notably the actinide concept, represented major theoretical contributions in the history of science. He held more than 40 patents — among them the only patents ever issued for chemical elements, americium and curium. He is also said to have received more than 50 degrees and honorary degrees in his lifetime. At one time, he was listed in the Guinness Book of World Records as having the longest entry in Marquis Who's Who in America. In February 2005, Seaborg was posthumously inducted into the National Inventors Hall of Fame.

Personal life

In 1942, Seaborg married Helen Griggs, the secretary of Ernest Lawrence.

Under wartime pressure, Seaborg had moved to Chicago while engaged to Griggs. When Seaborg returned to accompany Griggs for the journey back to Chicago, friends expected them to marry in Chicago. But, eager to be married, Seaborg and Griggs impulsively got off the train in the town of Caliente, Nevada for what they thought would be a quick wedding. When they asked for City Hall, they found Caliente had none—they would have to travel 25 miles north to Pioche, the county seat. With no car, this was no easy feat but, happily, one of Caliente's newest deputy sheriffs turned out to be a recent graduate of the Cal Berkeley chemistry department and was more than happy to do a favor for Seaborg. The deputy sheriff arranged for the wedding couple to ride up and back to Pioche in a mail truck. The witnesses at the Seaborg wedding were a clerk and a janitor.

Glenn Seaborg and Helen Griggs Seaborg had six children, of whom the first, Peter Glenn Seaborg, died in 1997. The others were Lynne Seaborg Cobb, David Seaborg, Steve Seaborg, Eric Seaborg, and Dianne Seaborg.

Seaborg was an avid hiker. Upon becoming Chairman of the Atomic Energy Commission in 1961, he commenced taking daily hikes through a trail which he blazed at the headquarters site in Gaithersburg, Maryland. He frequently invited colleagues and visitors to accompany him and the trail became known as the "Glenn Seaborg Trail."

He and his wife Helen are credited with blazing a 12 mile trail in the East Bay area near their Lafayette, California home. This trail has since become a part of the American Hiking Association's cross-country network of trails. Seaborg and his wife walked the trail network from Contra Costa County all the way to the California-Nevada border.

Seaborg was honored as Swedish-American of the Year in 1962 by the Vasa Order of America. In 1991, the organization named "Local Lodge Glenn T. Seaborg No. 719" in his honor during the Seaborg Honors ceremony at which he appeared. This lodge maintains a scholarship fund in his name, as does the unrelated Swedish-American Club of Los Angeles.

Seaborg kept a close bond to his Swedish origin. He visited Sweden every so often and his family were members of the Swedish *Pemer Genealogical Society*, a family association open for every descendant of the Pemer family, a Swedish family with German origin, from which Seaborg was descended on his mother's side.^[22]

He was elected a foreign member of the Royal Swedish Academy of Sciences in 1972.

Seaborgium

The element seaborgium was named after Seaborg by Albert Ghiorso, E. Kenneth Hulet, and others, who also credited Seaborg as a co-discoverer. It was so named while Seaborg was still alive, which proved controversial. He influenced the naming of so many elements that with the announcement of seaborgium, it was noted in *Discover* magazine's review of the year in science that he could receive a letter addressed in chemical elements: seaborgium, lawrencium (for the Lawrence Berkeley Laboratory where he worked), berkelium, californium, americium.^[23]

While it has been commonly stated that seaborgium is the only element to have been named after a living person, this is not entirely accurate; both einsteinium and fermium were proposed as names of new elements discovered by Albert Ghiorso while Enrico Fermi and Albert Einstein were still living. The discovery of these elements and their names were kept secret under Cold War era nuclear secrecy rules, however, and thus the names were not known by the public or the broader scientific community until after the deaths of Fermi and Einstein. Thus seaborgium is the only element to have been publicly named after a living person.

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Miscellany

Actinides in the environment

Actinides in the environment refer to the sources, environmental behaviour and effects of actinides in Earth's environment. Environmental radioactivity is not limited solely to actinides; non-actinides such as radon and radium are of note.

Inhalation versus ingestion

In general for the insoluble actinide oxides such as high fired uranium dioxide and MOX fuel if it is swallowed then it will pass through the digestive system with very little actinide dissolving. As the actinide oxide cannot dissolve, it cannot be absorbed into the body of the person or animal. With such an oxide the dose a person is committed to after a given intake of activity is higher for inhalation than for ingestion as the insoluble compound will remain in the lungs, where it will then irradiate the lung tissue.

Low fired oxides and soluble salts such as the nitrates can be absorbed with greater ease through the digestive system, so they are able to enter the bloodstream after being swallowed. If they are inhaled then it is possible for the solid to dissolve and leave the lungs. Hence the dose to the lungs will be lower for the soluble form.

Radon and radium in the environment

Radon and radium are not actinides—they are both radioactive daughters from the decay of uranium. Aspects of their biology and environmental behaviour is discussed at radium in the environment.

Thorium in the environment

In India, a large amount of thorium ore can be found in the form of monazite in placer deposits of the Western and Eastern coastal dune sands, particularly in the Tamil Nadu coastal areas. The residents of this area are exposed to a naturally occurring radiation dose ten times higher than the worldwide average.^[1]

Occurrence

Thorium is found in small amounts in most rocks and soils, where it is about three times more abundant than uranium, and is about as common as lead. Soil commonly contains an average of around 6 parts per million (ppm) of thorium. Thorium occurs in several minerals, the most common being the rare earth-thorium-phosphate mineral, monazite, which contains up to about 12% thorium oxide. There are substantial deposits in several countries. ^{232}Th decays very slowly (its half-life is about three times the age of the earth) but other thorium isotopes occur in the thorium and uranium decay chains. Most of these are short-lived and hence much more radioactive than ^{232}Th , though on a mass basis they are negligible.



Monazite, a rare-earth-and-thorium-phosphate mineral is the primary source of the world's thorium

Effects in humans

Thorium has been linked to liver cancer. In the past thoria (thorium dioxide) was used as a contrast agent for medical X-ray radiography but its use has been discontinued. It was sold under the name Thorotrast.

Uranium in the environment

Uranium is a natural metal which is widely found. It is present in almost all soils and it is more plentiful than antimony, beryllium, cadmium, gold, mercury, silver, or tungsten and is about as abundant as arsenic or molybdenum. Significant concentrations of uranium occur in some substances such as phosphate rock deposits, and minerals such as lignite, and monazite sands in uranium-rich ores (it is recovered commercially from these sources).

Seawater contains about 3.3 parts per billion of uranium by weight^[2] as uranium(VI) forms soluble carbonate complexes. The extraction of uranium from seawater has been considered as a means of obtaining the element. Because of the very low specific activity of uranium the chemical effects of it upon living things can often outweigh the effects of its radioactivity. Additional uranium has been added to the environment in some locations as a result of the nuclear fuel cycle and the use of depleted uranium in munitions.

Neptunium in the environment

Like plutonium, neptunium has a high affinity for soil.^[3] However, it is relatively mobile over the long term, and diffusion of neptunium-237 in groundwater is a major issue in designing a deep geological repository for permanent storage of spent nuclear fuel. ²³⁷Np has a half-life of 2.144 million years, so it is a long-term problem; but its half-life is still much shorter than those of uranium-238, uranium-235, or uranium-236, and ²³⁷Np therefore has higher specific activity than those nuclides.

Americium in the environment

Americium often enters landfills from discarded smoke detectors. The rules associated with the disposal of smoke detectors are very relaxed in most municipalities. For instance in the UK it is permissible to dispose of an americium containing smoke detector by placing it in the dustbin with normal household rubbish, but each dustbin worth of rubbish is limited to only containing one smoke detector.

In France a truck transporting 900 smoke detectors had been reported to have caught fire, it is claimed that this led to a release of americium into the environment.^[4] In the U.S., the "Radioactive Boy Scout" David Hahn was able to buy thousands of smoke detectors at remainder prices and concentrate the americium from them.

There have been cases of humans being contaminated with americium, the worst case being that of Harold McCluskey. It is interesting to note that Harold McCluskey did not die of cancer but of heart disease (which he had before the accident). It is likely that the medical care which he was given saved his life; because of the difference in the chemistry of americium (the +3 oxidation state is very stable) to plutonium (where the +4 state can form in the human body) the americium has very different biochemistry to plutonium.

The most common isotope americium-241 decays (half-life 431 years) to neptunium-237 which has a much longer half-life, so in the long term, the issues discussed above for neptunium apply.

Plutonium in the environment

Sources

Plutonium in the environment has several sources. These include:

- Atomic batteries
 - In space
 - In pacemakers
- Bomb detonations
- Bomb safety trials
- Nuclear accidents (such as Chernobyl)
- Nuclear crime
- Nuclear fuel cycle

Environmental chemistry

Plutonium, like other actinides, readily forms a plutonium dioxide (*plutonyl*) core (PuO_2). In the environment, this plutonyl core readily complexes with carbonate as well as other oxygen moieties (OH^- , NO_2^- , NO_3^- , and SO_4^{2-}) to form charged complexes which can be readily mobile with low affinities to soil.

- $\text{PuO}_2(\text{CO}_3)_1^{-2}$
- $\text{PuO}_2(\text{CO}_3)_2^{-4}$
- $\text{PuO}_2(\text{CO}_3)_3^{-6}$

PuO_2 formed from neutralizing highly acidic nitric acid solutions tends to form polymeric PuO_2 which is resistant to complexation. Plutonium also readily shifts valences between the +3, +4, +5 and +6 states. It is common for some fraction of plutonium in solution to exist in all of these states in equilibrium.

Plutonium is known to bind to soil particles very strongly, see above for a X-ray spectroscopic study of plutonium in soil and concrete. While caesium has very different chemistry to the actinides, it is well known that both caesium and many of the actinides bind strongly to the minerals in soil. Hence it has been possible to use ^{134}Cs labeled soil to study the migration of Pu and Cs in soils. It has been shown that colloidal transport processes control the migration of Cs (and will control the migration of Pu) in the soil at the Waste Isolation Pilot Plant.^[5]

See also

- Uranium in the environment
- Radium in the environment
- Background radiation

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