

AMERICIUM – FROM DISCOVERY TO THE SMOKE DETECTOR AND BEYOND*

Keith Kostecka, Columbia College-Chicago

Introduction

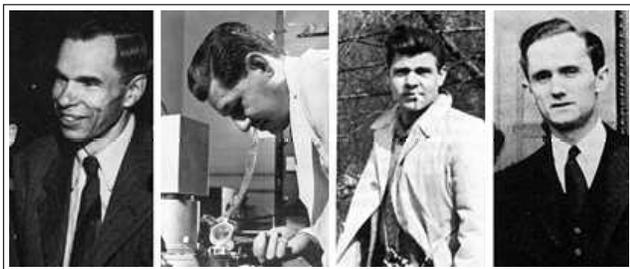


Figure 1. (left to right). Glenn Seaborg, Albert Ghiorso, Ralph James and Tom Morgan.

Since its isolation by Seaborg and his colleagues in 1944, americium has proven to be an element that is quite useful. Discussion of the discovery, announcement of and naming of this element, its characteristics, isotopes, applications [including in smoke detectors], use as a portable gamma ray source, and as a fuel for spacecraft will be described. The chemistry of americium and also work being done to reduce the radio-toxicity of the waste from the reprocessing of used nuclear fuel will also be noted.

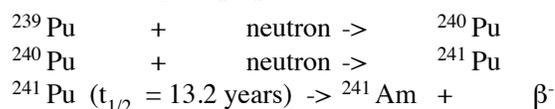
Discovery, Announcement, and Naming

Discovery

In late 1944, in what was the University of Chicago's wartime Metallurgical Laboratory [now Argonne Na-

tional Laboratory], Seaborg, Ghiorso, James, and Morgan (Fig. 1) were the first to "produce" the synthetic element number 95 (1 - 3). This was accomplished through the reaction seen in Figure 2

Figure 2. Seaborg led preparation of Americium-241.



[it is now known that Plutonium-241 has a half-life of 14.4 years (4)]. This discovery was verified by using tracer techniques, given that there were only a few billion atoms available of this new element to study (2). Element 95 was the fourth transuranium element to be discovered, and it was only isolated in amassable quantities in the fall of 1945 (5). It is fascinating to note that the method used to isolate this element warranted a patent in 1964 (6).

Announcement

Given that much of the work of Seaborg and his colleagues during WWII was directly related to the war effort, announcement of important discoveries such as new elements in the periodic table had to be delayed until after the war ended before the work could be de-classified.

This was done informally and unintentionally on live radio on the NBC game show "Quiz Kids" on November 11, 1945 (7). Seaborg, appearing as a guest on the show [which featured children with high IQs and included future (1962) Nobelist James D. Watson], was asked by

Richard Williams whether any new elements, in addition to plutonium and neptunium, had been discovered at Seaborg's laboratory during the war.

This question was very appropriate since the discovery information had been "prepared" for announcement at an American Chemical Society meeting on November 16. Seaborg answered Williams's question by saying that two new elements with atomic numbers of 95 and 96 had been discovered (8).

Naming

Element 95 was included in one more radio appearance before it finally received a name. Seaborg, appearing on the December 15, 1945 airing of the radio program "Adventures in Science," responded to the announcer's question as to whether elements 95 and 96 had been named by stating "...naming one of the fundamental substances of the universe is, of course, something that should only be done after careful thought" (7). The announcer then suggested that listeners should submit their ideas to the program. Those who sent in ideas received a free issue of *Chemistry* magazine that included Seaborg's technical paper and a newly revised periodic table. Ideas received by the program and submitted to Seaborg are shown in Table 1.

Table 1. Selected Proposed Names for Element 95

Big dipperain
Sunonium
Artifium
Artifician
Cyclo
Mechanicium
Curium
Americium

Ultimately, because of the position of element 95 in the periodic table and since its lanthanide homolog, europium, was named after Europe, it made perfect sense to Seaborg that element 95 be named "americium." Thus, it was so named!

Characteristics

Americium, the 95th element in the periodic table, is a synthetic solid metal having a silver and white luster that tarnishes slowly in dry air at room temperature (3). It is fairly malleable and has a relative atomic mass of 243. Selected properties of this element are listed in Table 2 (9 - 12).

Table 2. Selected Characteristics of Americium.

Density	13.69 g/cm ³
Melting point	1449 K
Boiling point	2284 K
Oxidation states	4 (+3, +4, +5 and +6)
Atomic radius	173 pm
Crystal structure	Hexagonal
Molar volume	17.78 cm ³ /mol
Heat of fusion	14.4 kJ/mol
Heat of vaporization	238.5 kJ/mol
Cost, pure	\$160/mg (Am-243)

Isotopes

Eighteen isotopes of the element have been characterized, the most stable [and useful] having masses of 243 and 241. Am-243 has a half-life of 7,370 years but has no broad commercial use. Am-241, termed the "most useful actinide isotope" by Navratil, Schulz, and Seaborg, and now available in kilogram quantities, has a half-life of 432 years (5, 13). It has an alpha activity approximately three times that of radium. When it is handled in gram quantities, it exhibits intense gamma activity but has not been found to cause cancer in humans (14). In addition, although it is fissionable, its critical mass of about 60 kilograms is much higher than that of isotopes of plutonium and uranium; and therefore Am-241 is a poor choice for use in a nuclear device.

Applications

The use (and possible future use) of this element can best be seen in four areas: a neutron source; alpha-ionizing radiation; gamma transmission properties; and as a potential fuel for spacecraft.

Neutron sources containing Am-241 that furnish alpha particles find use in oil well logging, determining soil density and moisture content, measuring moisture content of coke and concrete, and in the activation analysis of a variety of materials as well as for the testing of neutron counters (5, 15). Am-241 is also useful for its alpha-ionizing radiation ability. This is manifested in its applications to determine gas density, serve as an ionization detector in gas chromatography, aid in the preparation of luminous paint, determine the unifor-



Figure 3. Residential ceiling-mounted smoke detector.

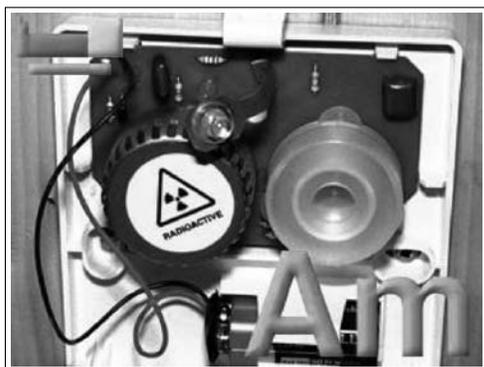


Figure 4. Inside a smoke detector.

mity of thin films, and help to determine the relative humidity of air (5).

Of all the applications of Am-241, however, there is one most familiar to householders everywhere: the smoke detector (Fig. 3 and 4). In a typical smoke detector, americium oxide is bonded to a substrate and exposed directly to the air inside (16, 17). In the sensing chamber the americium oxide ionizes the air so that it becomes a conductor of electricity. Electric current then flows between the two electrodes in the unit; but the electricity flow can be interrupted when tiny smoke particles enter the detector's chamber. If this occurs, the alarm circuit is triggered (5). Anyone having a working smoke detector in the home will have double the chance to survive a fire.

Am-241 has also been used as a portable gamma ray source in radiography. Possible uses are in medicine where gamma emission of Am-241 has allowed the determination of mineral content of bones, lipid content of soft tissues, and body composition (5). Other applications in radiography abound in mineralogy, soil science, and in hydrology (18). Of further interest is the use of this isotope in industrial gauging of materials [for possible internal defects] such as in analysis of metal castings and welded joints (Fig. 5). Imperfections in brake liners and in clutches in manual transmissions can also be detected through this process.

Another use, though with a different isotope, could be as an advanced nuclear rocket propulsion fuel through use of the Am-242m isotope. This work, demonstrated by scientists at Ben-Gurion University of the Negev, may allow trips from Earth to Mars in as little as two weeks (19)! This fairly rare nuclear material could likely maintain nuclear fission existing as an extremely thin metallic film while its high-energy, high-temperature fission fragments escape from the fuel and can thereby lead to faster interplanetary travel.

Chemistry of the Element

The chemistry of this element is best described through its synthesized compounds of Am-241 and in efforts to reduce radiotoxicity of spent nuclear fuel.

Compounds

The first compound of americium [$\text{Am}(\text{OH})_3$] was isolated in the fall of 1945 by Cunningham (5). A variety of halides, oxides, carbonates and sulfates have been prepared and are noted in Table 3 (20). It is apparent that the "preferred" charge for Americium in these compounds is +3.

Table 3. Selected Compounds of Americium

Oxides:	AmO_2 , Am_2O_3 , $\text{AmO}_{1.6-1.9}$
Halides:	AmF_3 , AmF_4 , AmO_2F_2 , AmCl_2 , AmCl_3 , AmOCl , AmBr_3 , AmBr_2 , AmI_2 , AmI_3 , AmOI
Carbonates:	$\text{Am}_2(\text{CO}_3)_3$, MAmOCO_3
Sulfates:	$\text{Am}_2(\text{SO}_4)_3$, $\text{MAm}(\text{SO}_4)_2$

More recent work has led to the preparation and study of nitrides, phosphides, sulfides, monochalcogenides, and mononpnictides of americium (21 - 24). This work has included the study of how pressure affects the nature of the element's 5f electrons (25) and even the pressure effects on the superconductivity of AnTGa_5 systems where $\text{An} = \text{Np}$, Pu and Am , while $\text{T} = \text{Co}$, Rh and Ir (26).



Figure 5. Gamma radiography.

Reducing Radio-toxicity

Given that americium and other transplutonium elements are responsible for much of the long-lived radiotoxicity of spent nuclear fuel, a great deal of work has [and is being] done on the extraction of americium (3). If americium and curium are so removed, the remaining spent fuel

would thus require a shorter isolation time. Efforts to address this challenge have involved the use of triazines and other compounds as potential extraction agents (27). The use of 2,6-di(5,6-dipropyl-1,2,4-triazin-3-yl)pyridine was reported to lead to a 99.95% removal of americium from a feed phase, while a synergistic mixture of di(chlorophenyl)dithiophosphinic acid and tri-*n*-octyl phosphine oxide as extractants led to a 99.996% removal (28). Researchers are also identifying molecules such as the Klaui ligand, which has the ability to extract actinides from the environment (Fig. 6). In fact, this compound begs the question: Computational Actinide Chemistry: Are we there yet (29)?

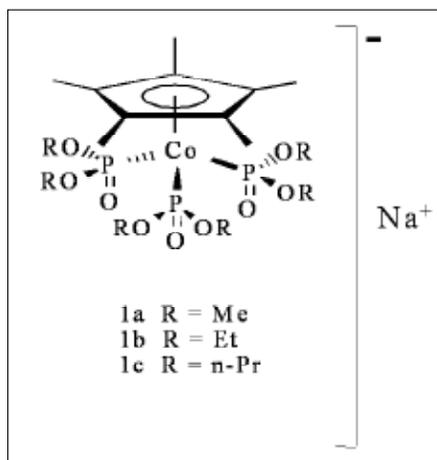


Figure 6. Structure of the Klaui ligand.

Conclusion

It has been clearly shown that americium is an element of significant interest through a consideration of its history from discovery to its applications and beyond.

ACKNOWLEDGMENTS

I wish to thank the Science and Mathematics Department at Columbia College Chicago and the Division of the History of Chemistry for their support.

REFERENCES AND NOTES

* Presented before the History of Chemistry Division at the 234th American Chemical Society Meeting, Boston, MA, August 19, 2007, HIST 001.

1. G. T. Seaborg and J. J. Katz, *The Transuranium Elements*, NNS-IV-14B, McGraw-Hill Book Co., New York, 1949.
2. T. K. Keenan. "Americium and Curium," *J. Chem. Educ.*, **1959**, 36, 27-31.
3. Americium; <http://en.wikipedia.org/wiki/Americium> (accessed May, 2008).

4. Science for the Critical Masses: How Plutonium Changes with Time. Available at <http://www.ieer.org/ensec/no-3/puchange.html> (accessed May, 2008).
5. J. D. Navratil, W. W. Schulz, and G. T. Seaborg. "The Most Useful Actinide Isotope: Americium-241," *J. Chem. Educ.*, **1990**, 67, 15-16.
6. Patent number 3,156,523, "Element 95 and Method of Producing Said Element." Available through <http://patft.uspto.gov/netahtml/PTO/srchnum.htm> (accessed May, 2008).
7. Americium: <http://pubs.acs.org/cen/80th/print/americi-unprint.html> (accessed May, 2008).
8. The author has yet to discover exactly what ACS meeting was meant here. There were no national ACS meetings during 1945.
9. It's Elemental – Americium: <http://education.jlab.org/itselemental/ele095.html> (accessed May, 2008).
10. Americium: <http://www.periodni.com/en/am.html> (accessed May, 2008).
11. Americium: <http://periodic.lanl.gov/elements/95.html> (accessed May, 2008).
12. Spectrum, Chemical Fact Sheet – Americium: <http://www.speclab.com/elements/americium.htm> (accessed May, 2008).
13. When Am-241 was first put up for sale in 1962 by the US Atomic Energy Commission, it cost \$1,500/gram.
14. ToxFAQs for Americium: <http://www.atsdr.cdc.gov/tfacts156.html> (accessed May, 2008).
15. Moisture and Density "Nuclear" Gauges Used in Road Construction: <http://www.epa.gov/radtown/gauges.html> (accessed May, 2008).
16. Health Physics Society: <http://www.hps.org/publicinformation/ate/q4738.html> (accessed May, 2008).
17. In fact, one gram of americium oxide provides enough active material for about 5,000 smoke detectors. This compound, in addition, gives a radiation dose to homeowners of essentially zero.
18. A Gamma-Ray Source for Use In Radiography: <http://www.freepatentsonline.com/EP1200966.html> (accessed May, 2008).
19. Extremely Efficient Nuclear Fuel Could Take Man To Mars In Just Two Weeks: <http://www.sciencedaily.com/releases/2001/01/010103073253.htm> (accessed May, 2008).
20. F. A. Cotton and G. Wilkinson, *Advanced Inorganic Chemistry – A Comprehensive Text*, John Wiley and Sons, New York, 1980.
21. Synthesis of actinide nitrides, phosphides, sulfides and oxides: <http://www.freepatentsonline.com/5128112.html> (accessed May, 2008).
22. L. Petit, A. Svane, W. M. Temmerman, and Z. Szotek. "Valency in Actinides," *Solid State Commun.*, **2000**, 116, 379-383.
23. L. Petit, A. Svane, W. M. Temmerman, and Z. Szotek, "Self-interaction Corrected Description of the Elec-

- tronic Properties of Americium Monochalcogenides and Monopnictides, *Phys. Rev. B*, **2001**, 63, 165107.
24. L. Petit, A. Svane, W. M. Temmerman, and Z. Szotek. "Electronic structure of Pu Monochalcogenides and Monopnictides," *Eur. Phys. J. B*, **2002**, 25, 139-146.
25. S. Heathman, R.G. Haire, T. Le Bihan, A. Lindbaum, K. Liftin, Y. Meresse, and H. Libotte. "Pressure Induces Major Changes in the Nature of Americium's 5f Electrons," *Phys. Rev. Lett.*, **2000**, 85, 2961-2964.
26. Pressure Effect on the Superconductivity of AnTGa Systems and Americium metal (An = Np, Pu, Am – T = Co, Rh, Ir): http://www.mrs.org/s_mrs/sec_subscribe.asp?CID=6210&DID=170299&action=detail (accessed May, 2008).
27. M. J. Hudson, M. G. B. Drew, M. R. St. J., Foreman, C. Hill, N. Huet, C. Madic, and T.G.A. Youngs. "The Coordination Chemistry of 1,2,4-Triazinylbipyridines with Lanthanide (III) Elements – Implications for the Portioning of Americium (III)," *J. Chem. Soc. Dalton Trans.*, **2003**, 1675-1685.
28. A. Geist, M. Weigl, and K. Gompper. "Effective Actinide (III)-Lanthanide (III) Separation in Miniature Hollow Fibre Modules. 7th Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, 2002. OECD Nuclear Agency. Available at <http://www.nea.fr/html/pt/docs/iem/jeju02/session2/SessionII-15.pdf> (accessed May, 2008).
29. Computational Actinide Chemistry: Are we there yet? http://www.eurekaalert.org/pub_releases/2007-08/dnnl-cac081307.php (accessed May, 2008).

ABOUT THE AUTHOR

Keith Kostecka is a Professor of Chemistry and Environmental Science in the Science and Mathematics Department, Columbia College Chicago, 600 S. Michigan Ave., Chicago, IL 60605-1996; kkostecka@colum.edu. An inorganic chemist by academic training and an analytical chemist through industrial experience, he is particularly interested in the application of chemical history to nonscience major instruction.

FUTURE ACS MEETINGS

March 22-26, **2009**—Salt Lake City, UT
August 16-20, **2009**—Washington, DC
March 21-25, **2010**—San Francisco, CA
August 22-26, **2010**—Boston, MA
March 27-31, **2011**—Anaheim, CA
August 28-September 1, **2011**—Chicago, IL
March 25-29, **2012**—San Diego, CA
August 19-23, **2012**—New York, NY
April 7-11, **2013**—New Orleans, LA
September 8-12, **2013**—Indianapolis, IN
March 16-20, **2014**—Washington, DC
September 7-11, **2014**—San Francisco, CA
March 22-26, **2015**—Denver, CO
August 16-10, **2015**—Boston, MA
March 13-17, **2016**—San Diego, CA
August 21-25, **2016**—Philadelphia, PA
April 2-6, **2017**, San Francisco
September 10-14, **2017**, St. Louis