Canadian Nuclear Society

Americium-241 vs. Plutonium-239 Fact Sheet

www.cns-snc.ca/ecc/cnsecc.html

$^{241}_{95}$Am & $^{239}_{94}$Pu

Americium-241 (^{241}Am) is used in very small quantities in household ionization smoke detectors. Americium is similar to plutonium (Pu) in many ways. While the public accepts the use of minute quantities of ^{241}Am in smoke detectors in their homes, the public reaction to transporting any quantity of ^{239}Pu under suitable controls is very different. A popular publication[1,2] commented that while both americium and neptunium could undergo fission, they are not under IAEA Safeguards. This fact sheet tries to put this issue in context.

^{241}Am emits both high-energy alpha radiation and low-energy gamma rays. The energetic alpha particles are absorbed within the smoke detector, while most of the gamma rays escape. The americium is secured from casual contact by the construction of the smoke detector. It is prepared as a metal oxide that is resistant to biochemical processes should it somehow be ingested.

Americium has atomic number 95 and an average atomic mass of 243. Metallic americium is a silvery metal, which tarnishes slowly in air and is soluble in acid. There are no stable isotopes of americium, and hence it is extremely scarce in nature. Of its 13 isotopes, ^{243}Am is the most stable, with a half-life of over 7500 years, although ^{241}Am, with a half-life of 470 years, was the first isotope to be isolated. (After one half-life, half of the original quantity of a radioactive isotope would have decayed, and half would remain.)

Plutonium has atomic number 94 and an average atomic mass of 240. Metallic plutonium is a silvery metal -- but not as bright as americium. This metal also tarnishes slowly in air and is soluble in acid. There are no stable isotopes of plutonium, and hence it is extremely scarce in nature. Trace quantities are found in uranium ore. Of its 16 isotopes, ^{244}Pu is the most stable, with a half-life of about 80 million years. Many of these isotopes will fission with thermal neutrons. Some isotopes fission with fast neutrons (like ^{241}Am does). ^{239}Pu has a half-life of 24,400 years and a high cross-section for thermal neutron fission. ^{239}Pu undergoes alpha decay with an energy of 5.243 MeV or spontaneous fission.

Source

Plutonium-241 (^{241}Pu), which forms about 12% of the one percent plutonium content of typical spent fuel from a light-water power reactor, has a half-life of 14 years, decaying to ^{241}Am through beta emission. (These proportions are different in a CANDU® heavy water reactor.) ^{241}Pu is formed in any nuclear reactor by neutron capture starting from uranium-238 (^{238}U). The steps are:

^{238}U + neutron => ^{239}U,
^{239}U by beta decay => ^{239}Np, Np - neptunium
^{239}Np by beta decay =>^{239}Pu,
^{239}Pu + neutron => ^{240}Pu,
^{240}Pu + neutron => ^{241}Pu.

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[1] Albright, David, and O'Neil, Kevin, "*Challenges of Fissile Material Control*," Institute for Science and International Security (ISIS), 1999.

[2] Rothstein, Linda, "Explosive Secrets," The Bulletin of the Atomic Scientists, **55**, No. 2, March/April, 1999.

Revised 2008 October

The ^{241}Pu decays (emitting a beta particle) both in the reactor and subsequently to form ^{241}Am. ^{239}Pu is a precursor to the formation of ^{241}Am.

Fissionable?

^{241}Am also decays by spontaneous fission, however this is very rare. ^{241}Am is considered to be fissionable[3] by fast neutrons. Thus, it is possible to conceive of a spherical assembly of ^{241}Am that would support a fission chain reaction if it were initiated with fast neutrons. A bare sphere critical mass of ^{241}Am would have a radius of about 11.5 cm and a mass of 83 kg. The alpha decay energy would be almost entirely trapped in this mass and would amount to approximately 11 W. While much of the soft gamma radiation would be absorbed by the dense metal, it still would be a very strong gamma source and would require shielding for safe handling. At the commercial price of ^{241}Am ($1500 US per gram) this quantity would cost approximately $124,000,000 if one could purchase it. This quantity is the amount of ^{241}Am in about 400 million smoke detectors. (At this quantity, one would expect a volume discount ... not to mention some strategic questions.)

Fissile

A spherical critical mass of ^{239}Pu would be approximately 8 kg, depending on the technology used. As ^{239}Pu has a much longer half-life, this would be a less intense radiation source than the similar sphere of ^{241}Am -- emitting less than 2% as much energy per unit time as the americium sphere would. It is much easier to handle (provided it is not contaminated with other isotopes).

Mixed Oxide Fuels

Mixed oxide fuels have been under development for many years. These fuels are in routine use at civilian power reactors in Europe and Asia. Experiments to irradiate such fuel materials have been performed at the Chalk River Laboratory in both the NRX and NRU reactors. In MOX fuel, the ^{239}Pu exists as an oxide, much like the ^{241}Am in the smoke detector, only in larger quantities.

CANDU power reactors derive a fraction of their power from the fissioning of ^{239}Pu that is generated in the fuel during its time in the reactor. This fraction is larger in a CANDU than in a Light Water Reactor because the thermal neutron flux in the fuel for a given reactor power is higher, and as the fuel is un-enriched, ^{238}U is more abundant. The reactor "breeds" fissile material from ^{238}U.

In the future, when uranium becomes less readily available, "breeding" of fissionable material and fuel cycles using other elements, e.g., thorium (already in limited use in India) will become important to nuclear power generation. Until the early 1970's, the supply of uranium was considered to be limiting in the near term, and the development of MOX fuel technology received greater emphasis by reactor suppliers, including AECL. Since that time, it has been considered to be of interest principally in countries that lack an indigenous uranium supply.

[3] Srinivasan, M. et al, "Systematics of Criticality Data of Special Actinide Nuclides Deduced Through the Trombay Criticality Formula," Nuclear Science and Engineering, **102**, 295-309, (1989).