Economical Production of Pu^{238}. Steven Howe [1], Jorge Navarro[1], Douglas Crawford[1], Terry Ring[2].
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Introduction: Every mission launched by NASA to the outer planets has produced unexpected results. The Voyagers I and II, Galileo, and Cassini missions produced images and collected scientific data that totally revolutionized our understanding of the solar system and the formation of the planetary systems. These missions have been enabled by the use of Plutonium-238 (Pu-238). The conversion of the radioactive decay heat of the Pu-238 to electricity provides a long lived source of power for instruments. Unfortunately, the supply of Pu-238 is about to run out. Developing a reliable supply of Pu-238 is crucial to almost all future space missions.

Radioisotopic Thermoelectric Generators (RTGs) have been used in the past for all missions past Mars to provide electrical power to the spacecraft. The upcoming Mars Science Laboratory will utilize Multi-Mission RTGs (MMRTGs) which can operate in the vacuum of space or in a planetary atmosphere. Because of the desire for no moving parts, reliability, and long life, these systems rely on thermocouples to convert heat to electricity and are inherently inefficient. Only about 6% of the thermal energy is converted into electricity. Consequently, the specific masses of the RTG and MMRTG are 200 kg/kWe and 357 kg/kWe respectively [1]. Thus, the power supplies can be a significant fraction of the platform mass.

Recent advances in Stirling engines at the NASA Glenn Research Center indicate that Advanced Stirling Radioisotope Generators (ASRGs) may provide 25% conversion efficiency [2]. ASRGs will reduce the amount of Plutonium-238 (Pu-238) required for a given power level by a factor of 4. However, ASRGs contain moving parts and may suffer from vibration issues along with shorter life-spans than MMRTGs. In addition, the specific mass of the ASRG is 141 kg/kWe.

Even with the implementation of ASRGs, the supply of Pu-238 is limited and will run out circa 2020 [3]. Currently, NASA and DOE have proposed to produce Pu-238 using the Advanced Test Reactor (ATR) and the High Flux Isotope Reactor (HFIR) reactors at the Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL) respectively. These reactors produce high fluxes of thermal neutrons and are very appropriate for Pu production. Recent estimates of actual production of Pu-238 indicate a rate of 1.5 kg/yr. at a cost of over $90M. The primary issues with using this approach are: 1) cost, 2) handling of the target materials, and 3) generation of large volumes and masses of radioactive waste.

The CSNR is investigating the design of an alternative approach to Pu-238 production via a NIAC Phase I grant. The alternative method will allow for larger quantities of Pu per year to be generated at a significantly reduced cost, will greatly reduce handling of the Neptunium target material, and will produce a vastly reduced waste stream. In addition, this method may allow a sufficient reduction in cost of facilities to the point that the entire operation can be funded from private venture. Thus, the government only pays for the final product not the infrastructure.

Concept Description

The process proposed by the US government for Pu production is a proven method which has been used in the past. In essence, a large target of several kilograms of Neptunium-237 (Np-237) is placed in the reactor for up to a year. Pu-238 is produced after neutron capture in the Np-237 via reactions:

Np-237 + n → Np-238

Np-238 –-> beta decay; 2.7 days half life -- > Pu-238

The problem with this process is that the Np-238 has a drastically large probability of fissioning before it decays. Thus, in long irradiations, around 80-90% of the Np-238 is destroyed before it can decay. This means that the targets have a large inventory of fission products making them highly radioactive and very hard to handle and process. Consequently, the facilities necessary to handle several kgs of highly radioactive neptunium targets and thousands of gallons of acidic waste are large and expensive [4].

An alternative method that would enable higher production efficiencies of the Pu-238, is to continuously flow an encapsulated aqueous solution containing dissolved Np-237 in nitric acid through a nuclear reactor in a water carrier stream. The encapsulated solution will make the separation process safer, cleaner and the sampling process more efficient. The encapsulation (made of some viable polymer) also provides another layer of thermal moderation to take advantage of the high thermal absorption cross section of ^{237}Np. If there is a pipe break in the water stream carrier it easy to recover the encapsulated sample bottle and because the flowing media is the same as the reactor moderator (Water), the cooling of the reactor is not contaminated which means there is no reactivity changes in the nuclear reactor. The process also allows for much smaller processing facility because smaller amounts are processed continuously and the material is not full of fission products.

The flowing target scenario is not possible to implement in the ATR or HFIR without major interruption of service and extensive cost. However, the flowing target can be implemented in a "TRIGA-type" reactor. Coupled with the cheaper processing facility, the entire complex is within the realm of private development. Initial calculations indicate that the 5 MW reactor can produce 1.5 kg/yr via this process at a significantly reduced capital cost and in a much shorter time. Conceivably, this method can be implemented within a 2 year interval and enable missions to Mars and beyond to continue.

References

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