

Letter to the Editor

Inertial fusion-assisted production of Plutonium 238

Abstract

It is proposed to assist and substantially increase the production of Plutonium 238 by inertial fusion inside a pipe made of stainless steel passing through the core of a conventional nuclear fission reactor, by injecting a stream of pellets of Neptunium 237 encapsulated liquid deuterium–tritium (DT) under high pressure. Then, if from both ends of the pipe, a pulse of multi-megajoule intense relativistic electron beams are injected, they will compress the pellets and heat the liquid DT to reach ignition, leading to a smoldering thermonuclear burn, releasing a burst of 14 MeV neutrons, converting the Neptunium 237 into Neptunium 238, which after leaving the pipe outside the reactor, will by radioactive decay be converted into Plutonium 238. This strategy permits that the surplus of neutrons are not lost, because they are absorbed in the bulk of the fission reactor and not lost into the environment.

Keywords: Inertial fusion confinement; Neptunium 238; Neutron bombardment; Plutonium 238; Radioisotope thermoelectric generator

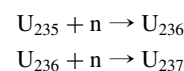
1. INTRODUCTION

An article entitled “NASA’s Plutonium (238) problem could end deep-space exploration” was published by *Wired* magazine in 2013. As described in the article, the Plutonium 238 problem “is so bad that affected researchers know it simply as ‘The Problem’”. The US stockpile of Pu 238 is only 36 pounds, with NASA’s “Curiosity” Mars rover containing about 10 pounds. “No more Plutonium 238 means not exploring perhaps 99% of the Solar system”. With a half-life of 87.7 years, the thermoelectric batteries driven by it can run for decades. Without them we could have not explored the outer planets, and the “New Horizon” space craft could not have captured surface images of Pluto. As Jim Adams, NASA’s deputy chief technologist has stated, “(Plutonium 238) is like a magic isotope. It’s just right”.

To stretch the dwindling supply of Plutonium 238, conventional thermoelectric batteries have been replaced by 25% more efficient Stirling engines developed by NASA’s Glenn Research Center in Cleveland. But these engines contain moving parts, which can interfere with the space craft’s instruments that have to deal with subtle phenomena.

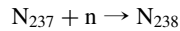
Because of the importance of Plutonium 238, not only for the exploration of the outer parts of the solar system, where solar energy collectors do not function, but ultimately also for interstellar missions, a large and replenishable supply of Plutonium 238 is highly in demand. It is here where electric pulse power techniques, developed for the achievement of thermonuclear fusion by inertial confinement offer a solution. As the Centurion–Halite nuclear underground experiments have shown, energies in the amount of 50 MJ delivered in about 10^{-7} – 10^{-8} s are needed for ignition of a small deuterium–tritium (DT) target. Energies of this magnitude and duration can be delivered by relativistic electron beams (REBs) through the discharge of large Marx generators. For the proposed production of Plutonium 238 through its conversion by neutron absorption of Neptunium 237, a micro-explosion with a smoldering thermonuclear burn might be sufficient, requiring a smaller amount of energy.

The same technique required for the production of Plutonium 238 from Neptunium 237, can be used for the production of Neptunium 237 from Uranium 235. The production of Neptunium 237 from Uranium 235 goes in two steps:



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with a 6.75-day radioactive decay of the Uranium 237 into Neptunium 237. The production of Plutonium 238 from Neptunium 237 goes in one step:



with a 2.1-day radioactive decay of Neptunium 238 into Plutonium 238.

The Oak Ridge National Laboratory has proposed a method for Plutonium 238 production, by the irradiation of Neptunium 237 in a high-flux thermal power reactor (Vondy *et al.*, 1964). Other groups working on the same problem are detailed in (Bickford *et al.*, 2013) and (Howe *et al.*, 2016). The crucial advantage of the proposed method to irradiate the Neptunium 237 with the extremely large but short duration neutron pulses from an inertial confinement fusion target is that with it a much larger production rate of Plutonium 238 is possible.

2. DESCRIPTION

The proposed concept is explained in Figures 1a and 1b. Figure 1a shows the arrangement of the stainless steel pipe passing through the core of a cylindrical nuclear fission reactor, with two openings at A and B, at the end of the pipe. A stream of in Neptunium 237 encapsulated liquid DT pellets P is injected at A, and following its compression and ignition by two intense REB, the Neptunium 238 containing burn product is exhausted from the pipe at B.

Figure 1b shows an enlargement of the pellet inside the pipe prior to its bombardment by the REBs. It has on its upper side a conical segment filled with some lower atomic weight ablator, which upon the bombardment by the electron beam accelerates and propels the pellet to a high speed in the vertical downward direction, in addition to its compression. It

permits the REB to enter into the pellet and heat the DT to a high temperature by the two-stream instability, with further heating done by the implosion of the pellet.

Following its ignition and burn, the Neptunium 238 containing debris is exhausted from the lower end B of the pipe.

For the conversion of Uranium 235 into Neptunium 237, the same configuration can be used by replacing the Neptunium 237 with Uranium 235.

3. SOME NUMBERS

To demonstrate the superiority of the proposed concept, it must be compared to the conventional method where Neptunium 237 is placed into a high neutron flux nuclear fission reactor. A typical value for the neutron flux of such a reactor is:

$$\phi_r \simeq 10^{14} \text{ cm}^2 \text{ s}^{-1} \tag{1}$$

and the time T the Neptunium 237 is exposed to this neutron flux given by

$$\phi_r T \simeq 10^{14} T \text{ cm}^{-2} \tag{2}$$

This value must be compared with the ϕT product of the inertially confined Neptunium, where ϕ is the neutron flux of the DT micro-explosion, and τ the inertial confinement time.

The generation of the neutrons by the DT fusion reaction is given by:

$$\frac{dn}{dt} = \frac{1}{4} n^2 \langle \sigma v \rangle, \tag{3}$$

where for the maximum of the cross section multiplied by the collision velocity one has:

$$\sigma v \simeq 10^{-15} \text{ cm}^3 \text{ s}^{-1}. \tag{4}$$

Integrating (3) over the inertial confinement time τ , one has for the neutrons released:

$$\Delta n = \frac{1}{4} n \tau \langle \sigma v \rangle n. \tag{5}$$

For breakeven, one has according to the Lawson criterion:

$$n \tau \geq 10^{14} \text{ s cm}^{-3}. \tag{6}$$

Hence for (5):

$$\Delta n \simeq \left(\frac{1}{4}\right) 10^{-1} n. \tag{7}$$

To obtain the neutron flux released by the DT micro-explosion, one has to multiply (7) with the velocity $v_0 = 5 \times 10^9 \text{ cm s}^{-1}$ of the 14 MeV DT fusion neutrons. One obtains:

$$\phi \simeq 10^8 n. \tag{8}$$

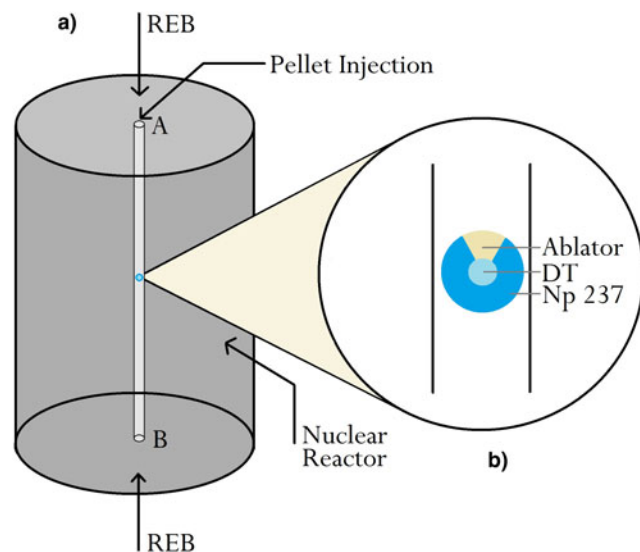


Fig. 1. Diagram of proposed concept.

For a modest twofold compression of the liquid DT from $n = 5 \times 10^{22} \text{ cm}^{-3}$ to $n = 10^{23} \text{ cm}^{-3}$, one thus has:

$$\phi \approx 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \quad (9)$$

and with (6) for the inertial confinement time $\tau \approx 10^{-9} \text{ s}$:

$$\phi\tau \approx 10^{22} \text{ cm}^{-2} \quad (10)$$

To make $\phi_r T = \phi\tau$ one obtains a value for T :

$$T = \left(\frac{\phi}{\phi_r} \right) \tau \quad (11)$$

with $\phi/\phi_r = 10^{17}$ and $\tau = 10^{-9} \text{ s}$, one finds that $T = 10^8 \text{ s}$ or more than 10 years. This number shows better than anything else the superiority of the proposed concept, and for that reason it may even work with a smoldering DT burn. Such a smoldering burn may in any case be necessary to prevent the micro-explosion from becoming too large, damaging the reactor.

One other advantage of this proposed concept is that it could be added to a nuclear power plant, whereby the surplus of neutrons released in the micro-explosion is not lost but absorbed and used to enhance the fission burn in such reactors.

4. CONCLUSION

It is shown that the inertial confined fusion assisted inside of a reactor would greatly enhance the production of Plutonium 238, urgently needed by NASA for its deep-space exploration missions. To let the inertial confinement fusion micro-

explosions take place inside a fission power reactor, would greatly improve the power output of such reactors.

Better compression and ignition may be achieved by using ion beams instead, to be produced at high intensity with Marx generators and magnetically insulated diodes. For a continuous operation, one may use multi-GeV Uranium 235 ion beams below the Alfvén current, and a fusion burn along the entire length of a tube filled with DT gas under high pressure into which the ion beam is projected.

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