TRANSMUTING NUCLEAR WASTE BY USE OF A QUASI-SUPERCONDUCTOR

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Ionization potential is customarily associated with the work required to remove electrons from atoms, but in a series of recent papers by A. Widom and L. Larsen, electron captures are shown to occur at ionization potential. Theirs is a wet method, but this paper will show how a dry method using quasi-superconductors should achieve the same objective. The method will be applied to the transmutation of nuclear waste.

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Indications are that Sweden may be the first to bury canisters of high-level nuclear waste deep underground. Other countries soon to follow are expected to be Finland, France, and the U.S. Any program that offers to reduce the volume of waste to bury is welcomed. One of the ways to decrease the amount of nuclear waste is to transmute it, and this is done in small quantities in nuclear reactors and in particle accelerators, but we need a simpler, faster, and more economical way to treat waste on an industrial scale. Perhaps such a method is on the horizon.

A recent paper shows how hydrogen adsorbed onto a metal surface can electrically convert the hydrogen to neutrons [1]. A material to be transmuted, such as technetium-99, for example, would be placed near this neutron source and be transformed to stable, non-radioactive ruthenium in the series of reactions shown below:

$$^{99}\mathrm{Tc} + n \rightarrow {}^{100}\mathrm{Tc}\,, \tag{1}$$

$$^{100}\mathrm{Tc} \rightarrow {}^{100}\mathrm{Ru} + e\,. \tag{2}$$

Technetium-99 is a migratory radioactive waste product, which means it can be buried in one country and move to another, so its destruction is imperative. The conversion shown above can be accomplished in minutes, compared to technetium-99's half-life of over 200,000 years.

Ref. [1] describes a wet method to generate neutrons, which is a welcomed advancement, but we need to develop a dry method to accomplish the same because use of a chemical to treat nuclear waste simply generates more nuclear waste. Superconductors are a means to absorb the resonance frequency of hydrogen atoms to produce neutrons. The enhanced electron mass of $m = 2.5\, m_0$ required for hydrogen-to-neutron conversion is provided by the relativistic mass increase as the electron descends toward the nucleus according to

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}\,. \tag{3}$$

Superconductors have been known for the past 50 years to absorb electronic frequencies of atoms [2]. It will be shown here that a near-superconductive cylindrical device, can achieve conversion of hydrogen to neutrons and transmute nuclear waste.

The first step is to load hydrogen on the walls of the inner cavity at a packing density of 10^{22} cm^{-3} [3]. Carbon nanotubes mats are selected for this purpose because they are well-known to adsorb atomic hydrogen [4]. This quasi-superconductor's function is to absorb hydrogen's resonance frequency and carry the energy to an outer casing, which serves as an energy sink. The instigation energy required is 13.6 eV. At that potential, according to the teaching of Ref. [1], hydrogen's orbital electron begins its collapse into the nucleus. Lending support to the Widom–Larsen theory is Ohtsuki's finding of shortened half-life of ^{7}Be believed due to induced electron capture [5]. The nucleus of hydrogen, of course, is a solitary proton, and the reaction produces neutrons according to the following scheme:

$$p + e \to n\,, \tag{4}$$

which neglects the neutrino.

To obtain the maximum possible efficiency, the device is rotated like a cement mixer to ensure as much contact of the technetium with neutrons as possible. The change from ^{99}Tc to ^{100}Ru actually takes only 17 seconds. The end-product is then removed; the inner cavity is reloaded with hydrogen; and the next batch is inserted.

A voltage is applied across a near-superconductor operational at 300 K. The objective in selecting the conductor is to obtain conduction electrons with as long a mean-free-path as possible. Water is passed over the device for cooling.

While it is realized that not all types of radioactive waste, such as ^{129}I ($^{129}\mathrm{I}+n \rightarrow {}^{130}\mathrm{I} \rightarrow {}^{130}\mathrm{Xe}+e$; $t = 12.5$ hours), will transmute as simply as the ^{99}Tc example, the more waste we can eliminate means the less we have to bury.

Looking now at the preferred embodiment of the device, on the basis of conduction-electron contribution, carbon at 300 K should be nearly one hundred times more electrically resistive than it is. Professor Guo-meng Zhao of California State University at Los Angeles claims carbon is a partial superconductor at room temperature [6]. That is, it appears that some percentage of electrons in the conduction band form Cooper pairs. In that case, carbon nanotubes and graphene sheets, which restrict electron motion to essentially one dimension, should enhance and maintain the pairing. Ebbesen [7] found some multi-walled nanotubes (MWNT) with only 200 Ω resistance, which is rather astonishing, considering that the resistance should be at least one hundred times that. If we think of the multi-shells in a MWNT as conductors in parallel, the shell with the most electron pairs would tend to short out the others. A MWNT with a near-zero resistance shell would, in essence, be a practical superconductor at elevated temperatures. Based on his individual-shell studies, Zhao finds the outermost shell offers the least resistance and the longest mean free path for electrons, which is exactly the property we wish to exploit.

Carbon nanotubes can be grown perpendicular to a substrate [8]. Such structures are called mats or nanotube farms. The tubes used to stick together, but that problem has been resolved [9]. Carbon nanotubes seem to bond particularly well to nickel [10].

Hydrogen gas is loaded into the central cavity of the device at a pressure of 1 barn for six minutes [11]. Carbon is known for its hydrogen uptake capability (see Ref. [4]).

A laboratory-scale transmuter of dimensions 1 meter length, 11-centimeter inner-cavity diameter, and 31-centimeter outer-casing diameter is modeled for illustrative purposes. ^{99}Tc is introduced into the cavity as a disperse system of fine particles at a density of 10 g/l. Industry typically makes technetium particles of 50–100 microns, although finer particles would reduce cycle time and improve transmutation efficiency.

According to Ref. [3], the neutron formed from hydrogen adsorbed on a surface has a long mean free path. By rotating the transmuter about the longitudinal axis, all particles have an even chance of becoming transformed to ruthenium, and generation of hot spots is prevented.

The total heat of reaction of Eqs. (1) and (2) is 9.993 MeV. Only 2% of the ^{99}Tc is in contact with the cavity wall at any time, so water cooling at a flow rate of 4 l/sec should be sufficient. Near 100% transmutation will occur in 2.5 hours. Since the cavity volume is nearly 10 liters, at the end of the cycle period, we will have treated 100 grams, or 8.7 cm^3 of technetium.

Ref. [12] discusses that neutron production rate when a palladium film is used is 10^{13}–10^{14} per cm^2. This is one neutron per palladium atom. Considering that each carbon nanotube of the transmuter will consist of millions of atoms, the neutron production will be near Avagadro's number. Even if the unit consumes 10^{14} neutrons per second, there are enough neutrons to last over a million seconds.

Electrical current through each nanotube should not exceed 1 μA (see Ref. [6]). For that reason, total current for the unit should not surpass 10 amperes. Higher voltages can, of course, be imposed, and it is suggested that a sweep circuit with several kV capability be employed if necessary.

Once the neutrons form, the substantial chemical potential between the carbon and the technetium surfaces allow the ^{100}Tc to form, with subsequent production of stable, nonradioactive ruthenium. Success with this system will allow us to tackle the ^{129}I problem.

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