White Paper

Lattice Confinement Fusion and Fusion-Fast-Fission Energy Source Development

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Abstract

NASA and the US Navy have demonstrated Lattice Confinement Fusion (LCF) and the Fusion-Fast-Fission of natural uranium and thorium. Both methods build upon decades of research, and the latter benefits from conventional nuclear fission and fusion results. However, this nascent technology doesn't require fissile isotopes and avoids nuclear weapons proliferation concerns from uranium ^{235}U isotopic enrichment or plutonium ^{239}Pu separation. Of particular note, LCF doesn't need power hungry magnets, lasers, or particle beams. Potentially, it could provide watts to hundreds of kilowatts of electrical power and process heat suitable for space power and high I_{sp} nuclear electric propulsion (NEP) as well as distributed terrestrial power. Finally, there are indications that LCF fast-fission products are more benign than those of conventional fission reactors. Our goal is to scale the reactions and increase the power output through higher temperature operation and increased material masses.

Background

Co-deposition, or the simultaneous electrolytic reduction and loading of palladium and deuterium, was invented by the US Navy as US Patent 8,419,919, "System and Method for Generating Particles". This protocol is one means of loading hydrogen isotopic fuel at very high densities in solid lattices, including thorium and uranium. Building upon three decades of research conducted with the US Navy SPAWAR [SZPA91], [MOSI16], the Naval Surface Warfare Centers [DECH15], [DECH21] and the NASA Glenn Research Center [STEI20], [SMIT21] we have continued to explore, observe, model and understand LCF science. We have characterized the fusion, activation and fast-fission products through experimental nuclear product observations and material assays, and modeled reactions using SRIM/TRIM, Density Functional Theory (Quantum Espresso) [DECH15], LANL Monte-Carlo Nuclear Modeling (MCNP®) and CERN GEANT-4 [BARA21] codes.

Goal

Our goal is to determine whether Lattice Confinement Fusion or Fusion-Fast-Fission technologies can be scaled to demonstrate power within three years. Lattice Confinement Fusion fast neutrons [MOSI09], [STEIN20], uranium fission [MOSI16], and activation products [MOSI19], [STEI20] have already been observed. We're working with Los Alamos National Laboratory on augmenting the MCNP® code to model electron-screened fusion reactions [LIPO11], [SCHE19] based upon our publications [PINE20] and fusion modeling tables [MILO12] supporting ITER[4]. We are currently using the real-time neutron spectroscopy [BARA21] developed for the previous bremsstrahlung-initiated fusion campaigns [STEI20] with the co-deposition protocol while exploring various reaction triggers and manufacturing LCF active nano-materials.

Science

Lattice Confinement Fusion relies upon heavily deuterated materials whose cold, neutral plasma densities approach electron Fermi-degeneracy of 10^{23}/ions cm^3 [PINE20]. Fermi-degeneracy, a quantum mechanical electron phenomena, occurs in the conduction bands of metals and prevents White Dwarf stars from collapsing. In turn, having fusion-ready, electron-screened isotopes at high density reduces the

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fusion Coulomb barrier and enhances fusion rates [LIPO11],[SCHE19]. The resulting fusion fast neutrons [MOSI09] have fissioned fertile actinides [MOSI19].

Over 1000 co-deposition related experiments have been successfully conducted in US Federal laboratories [DECH21], universities, in industry, and several foreign countries. Building upon this, we are exploring Lattice Confinement Fusion scaling in nanomaterials and the fast fission of uranium and thorium. Our diagnostics include real-time neutron scintillator spectroscopy [BAYA20], time-of-flight and materials assays including high purity germanium gamma ray detectors (HPGe), SEM/EDX and ICP-OES.

Research and Development

We have manufactured and initially triggered LCF-active nanomaterials and fertile actinides. We anticipate scaling the actinide co-deposition system from < 100 mg [MOSI19] of depleted uranium or thorium, to 1 and then 10 grams. Second, we will increase the operating temperature of devices from < 100 degrees Celsius at atmospheric pressure to higher temperatures with eutectic salts, and to high pressures and temperatures with nanomaterials. The fusion-augmented MCNP® and GEANT-4 codes allow modeling the most effective materials and geometry for the highest power.

Experiments have been conducted at the NASA Glenn Research Center - Lewis Field near Cleveland, OH and the Armstrong Test Facility near Sandusky, OH. We are currently using facilities and instrumentation developed for the previous NASA SMD Advanced Energy Conversion Project and the current Lattice Confinement Fusion Project. Additional analyses and experiments have been conducted in GEC laboratory facilities in San Diego, CA and at the University of Texas, Austin, Nuclear Engineering Teaching Laboratory.

Technology Readiness Level

The current level of research is at NASA TRL 2 with over 60 US and foreign peer-reviewed papers published regarding the patented and related protocols', experiments and modeling. We expect to reach TRL 5 after three years by demonstrating scaled output with modeling and extended lifetime experiments. Higher temperature operation is necessary for thermal to electric conversion efficiency such as with Advanced Stirling Engines [GIBS20] or closed Brayton Cycles.

NASA has supported the underlying LCF science for a decade. However, Lattice Confinement Fusion and fusion-fast-fission technologies are the next steps to solve NASA, NRO, Navy, Army, US Space Force and commercial energy needs. Although other agencies like DARPA have funded limited research, and ARPA-E has expressed interest, NASA has developed an unmatched team and key facilities. By advancing this research into a technology, NASA builds on its capabilities, solves its problems, and in turn attracts additional public and private partners. World-wide, NASA is viewed as working for all of humanity by forging and deploying new technologies.

Research Activities

The fundamental research began thirty years ago with the US Navy NOSC/SPAWAR-PACIFIC and resulted in two patents followed by several NCRADAs, and two NASA Space Act Agreements. Related research was conducted under the NASA Science Mission Directorate Advanced Energy Conversion Project and has continued under the Planetary Exploratory Science Technology Office, Lattice Confinement Fusion Project. This research continued with the Naval Surface Warfare Centers, one under NASA subcontract and the other most recently funded by DARPA.

In addition, the Anthropocene Institute has supported the university undergraduate Trackers STEM Program™ that also uses US Patent 8,419,919, "System and Method for Producing Particles" [MOSI18]. The European Union HORIZON 2020 Program is supporting two, multi-year efforts [HORI74] one of which uses the co-deposition protocol [HORI84] following the basis of the Trackers Program™. The US Army has funded a related program using co-deposition. Most recently, Forsley, Benyo and Mosier-Boss were invited to give presentations at a two-day DoE ARPA-E Workshop on Low Energy Nuclear Reactions [ARPA21] on nanomaterials, deuterium gas pumping and co-deposition, respectively.

The development of LCF as a technology is significant to both terrestrial power and heat production for DoD as well as NASA and NRO Programs. A compact, long-lived, extensible power source is useful for distributed terrestrial power and necessary for NASA deep space missions. By eliminating the need for enriched uranium, LCF reduces the safety, security and launch costs for future NASA missions employing fission reactors while using the power conversion and heat dissipation fast-fission infrastructure [GIBS20]. LCF eliminates the need for, and proliferation issues of, uranium enrichment.

Raison d'être

Lattice Confinement Fusion presents an opportunity to address numerous concerns across diverse problem areas. For DoD and NASA, the logistics of continually delivering energy sources to distant locations are one of the primary challenges associated with their missions. The public will benefit from an economical, safe, clean, and virtually unlimited power source to reduce both pollution and our reliance on fossil fuels. LCF would reduce the burden on the electrical grid from the booming trend towards vehicle electrification. It eliminates the risks of fission and its products, doing so on a far smaller scale than large tokamaks. The US Government, European Union and multiple industries in the US and in Japan are exploring various forms of Lattice Confinement Fusion. *This is a pivotal time*.

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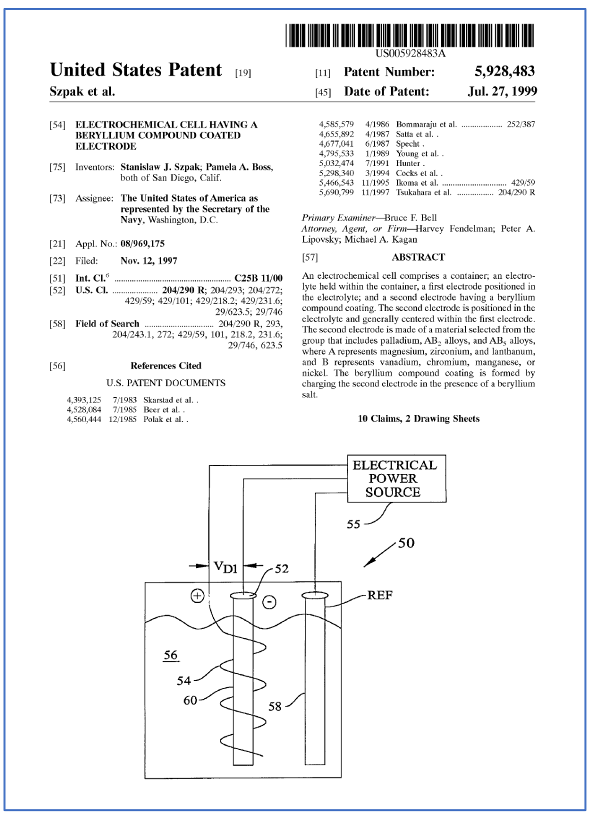

US005928483A

United States Patent [19] **Szpak et al.**

[11] **Patent Number: 5,928,483**
[45] **Date of Patent: Jul. 27, 1999**

[54] **ELECTROCHEMICAL CELL HAVING A BERYLLIUM COMPOUND COATED ELECTRODE**

[75] Inventors: **Stanislaw J. Szpak; Pamela A. Boss,** both of San Diego, Calif.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[21] Appl. No.: **08/969,175**

[22] Filed: **Nov. 12, 1997**

[51] **Int. Cl.**[6] **C25B 11/00**
[52] **U.S. Cl.** .... **204/290 R**; 204/293; 204/272; 429/59; 429/101; 429/218.2; 429/231.6; 29/623.5; 29/746
[58] **Field of Search** .... 204/290 R, 293, 204/243.1, 272; 429/59, 101, 218.2, 231.6; 29/746, 623.5

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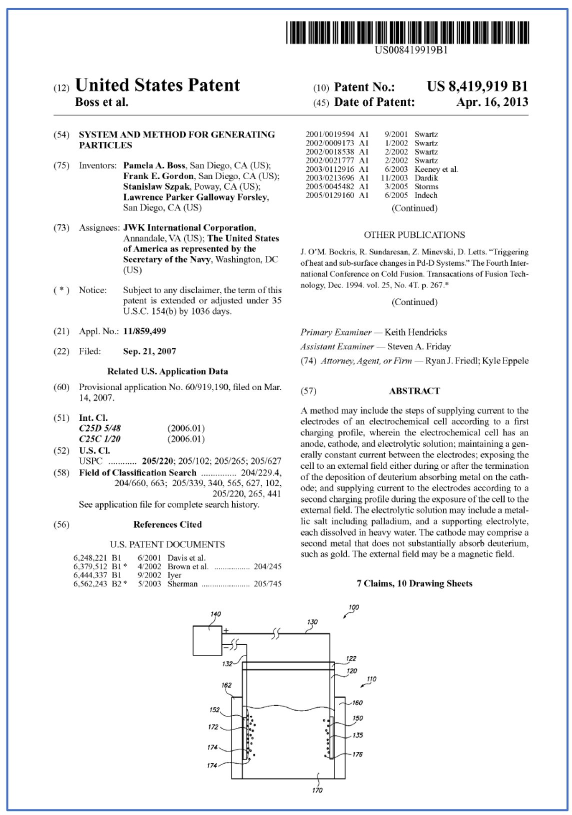
[57] **ABSTRACT**

An electrochemical cell comprises a container; an electrolyte held within the container, a first electrode positioned in the electrolyte; and a second electrode having a beryllium compound coating. The second electrode is positioned in the electrolyte and generally centered within the first electrode. The second electrode is made of a material selected from the group that includes palladium, AB_2 alloys, and AB_5 alloys, where A represents magnesium, zirconium, and lanthanum, and B represents vanadium, chromium, manganese, or nickel. The beryllium compound coating is formed by charging the second electrode in the presence of a beryllium salt.

10 Claims, 2 Drawing Sheets



US008419919B1

(12) **United States Patent** **Boss et al.**

(10) **Patent No.: US 8,419,919 B1**
(45) **Date of Patent: Apr. 16, 2013**

(54) **SYSTEM AND METHOD FOR GENERATING PARTICLES**

(75) Inventors: **Pamela A. Boss**, San Diego, CA (US); **Frank E. Gordon**, San Diego, CA (US); **Stanislaw Szpak**, Poway, CA (US); **Lawrence Parker Galloway Forsley**, San Diego, CA (US)

(73) Assignees: **JWK International Corporation**, Annandale, VA (US); **The United States of America as represented by the Secretary of the Navy**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1036 days.

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(52) **U.S. Cl.**
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(58) **Field of Classification Search** 204/229.4, 204/660, 663; 205/339, 340, 565, 627, 102, 205/220, 265, 441
See application file for complete search history.

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(57) **ABSTRACT**

A method may include the steps of supplying current to the electrodes of an electrochemical cell according to a first charging profile, wherein the electrochemical cell has an anode, cathode, and electrolytic solution; maintaining a generally constant current between the electrodes; exposing the cell to an external field either during or after the termination of the deposition of deuterium absorbing metal on the cathode; and supplying current to the electrodes according to a second charging profile during the exposure of the cell to the external field. The electrolytic solution may include a metallic salt including palladium, and a supporting electrolyte, each dissolved in heavy water. The cathode may comprise a second metal that does not substantially absorb deuterium, such as gold. The external field may be a magnetic field.

7 Claims, 10 Drawing Sheets

Biographies

LAWRENCE FORSLEY is the NASA Lattice Confinement Fusion (LCF) Project *Deputy Principle Investigator* and previously the *Lead Senior Experimental Physicist* for the AEC Project. He is a *Research Fellow* at the University of Texas, Austin, Nuclear Engineering Teaching Laboratory, a *Co-PI* with the Naval Surface Warfare Centers and previously US Navy SPAWAR-Pacific, and *CTO* of Global Energy Corporation. During the past 45 years, he has developed control and diagnostic systems for fusion research at the Laboratory for Laser Energetics (*Group Leader,* Omega laser fusion), Lawrence Livermore National Laboratory (*Consultant,* TMX-U/MFTF-B mirror fusion) and Max-Planck-Institut für Plasmaphysiks (*Visiting Scientist,* ASDEX tokamak) as well as for a modular bremsstrahlung source for the Defense Nuclear Agency. As *PI* he observed time-resolved, sonoluminescence-induced gamma rays at the Naval Research Laboratory and has specialized in temporally, spatially, and spectrally resolving IR through gamma ray energy photons, charged particles and neutrons.

THERESA BENYO is the Lattice Confinement Fusion Project *Principal Investigator* and an *analytical physicist* with NASA GRC. During the prior AEC Project she was the *nuclear diagnostics lead* conducting nuclear diagnostics including gamma spectroscopy, alpha/beta detection and half-life determination. She carried out nuclear Monte Carlo and Density Functional Theory modeling and oversaw material assays. Previously, she developed magnetohydrodynamic (MHD) models for hypersonic flight, electric and nuclear propulsion, and nuclear power for space. She has been a *Project Manager* for several programs at NASA GRC. She holds Ph.D., M.A. and B.S. degrees in Physics from Kent State University and an MS in Computer Science from Case Western Reserve University.

PAMELA MOSIER-BOSS is a retired *Scientist* from U.S. Navy SPAWAR-Pacific. She is currently a *Senior Scientist* for Global Energy Corporation. She has conducted research in the area of low energy nuclear reactions (LENR) for the past 32 years. In this research, she and her colleagues have employed the co-deposition process that was pioneered by Dr. Stanislaw Szpak. In the co-deposition process, palladium is electroplated onto a metal substrate in the presence of evolving deuterium gas. The resultant palladium nanoparticles load instantly with deuterium achieving the high D/Pd loadings and high deuterium flux inside the lattice to initiate LENR. Using the co-deposition process, Mosier-Boss and her colleagues have reported on the evidence of excess heat, tritium, X-ray/gamma-ray emissions, transmutation, charged particles, and neutrons. These results have been published in over 45 peer-reviewed journal articles. She holds a Ph.D. degree in analytical chemistry from Michigan State University and B.S degrees in chemistry and biology from Kent State University.

BRUCE STEINETZ is a *Senior Technologist* at NASA Glenn and is an adviser to the Lattice Confinement Fusion (LCF) Project. Dr. Steinetz served as the *Principal Investigator (PI)* for the Advanced Energy Conversion (AEC) project during its 5 year period, which serves as the basis for the current LCF project. During the AEC project, the Team accomplished several noteworthy achievements including triggering (d-d) fusion reactions in a "locally hot-globally cold" environment by exposing deuterated metals to bremsstrahlung radiation. The *Phys Rev C* reviewers noted the significance of inducing fusion reactions using only low-cost equipment. The Team confirmed NAVY SPAWAR findings of nuclear reactions with electrolytic co-deposition of palladium and deuterium onto a wire cathode. Dr. Steinetz and Team are now deploying neutron scintillator spectrometers to measure the co-deposition neutron energy and production rate. Dr Steinetz supports the nation's hypersonic research priorities building on 35+ years of high temperature materials and structures expertise. He holds a Ph.D., M.S., and B.S. degrees in Mechanical and Aerospace Engineering from Case Western Reserve University.