PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G21B 1/00 — A1

(11) International Publication Number: WO 91/14267

(43) International Publication Date: 19 September 1991 (19.09.91)

(21) International Application Number: PCT/US91/01642

(22) International Filing Date: 12 March 1991 (12.03.91)

(30) Priority data:
492,651 13 March 1990 (13.03.90) US

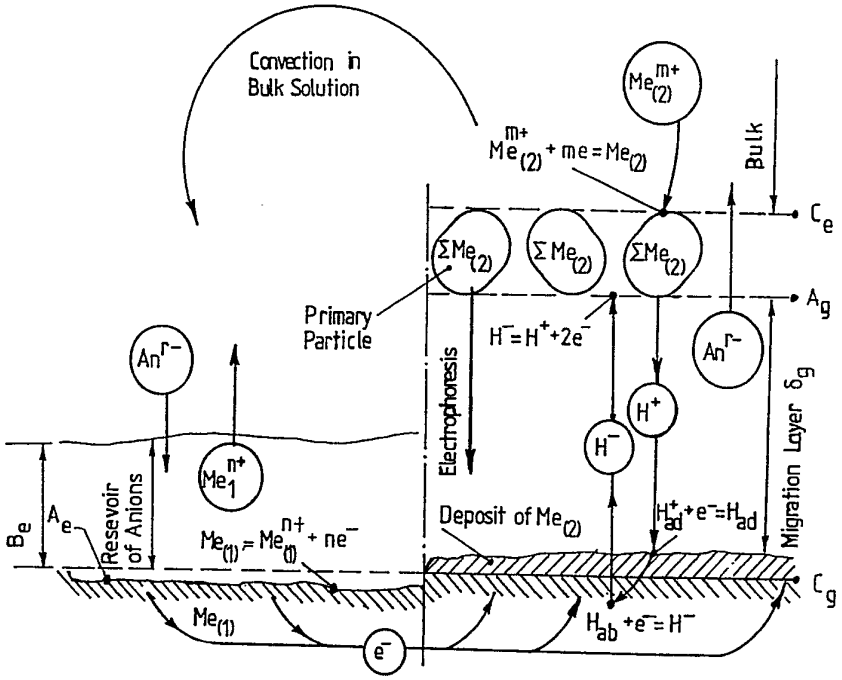
(71)(72) Applicant and Inventor: KHUDENKO, Boris, M. [US/US]; 744 Moores Mill Road, Atlanta, GA 30327 (US).

(74) Agent: ROSENBERG, Sumner, C.; Needle & Rosenberg, 133 Carnegie Way, N.W., Suite 400, Atlanta, GA 30303 (US).

(81) Designated States: AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH (European patent), CM (OAPI patent), DE (European patent), DK (European patent), ES (European patent), FI, FR (European patent), GA (OAPI patent), GB (European patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL (European patent), NO, PL, RO, SD, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent).

Published
With international search report.

(54) Title: METHOD AND APPARATUS FOR NUCLEAR FUSION



(57) Abstract

The present invention relates to a method and apparatus for cold nuclear fusion in which fusionable particles located within an electrolyte are accelerated by local electromagnetic fields in a migrational transport layer. This migrational transport layer can be induced either by creating a cementation system, applying an outside source of current to an electrode system, or a combination of both.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**ES**	Spain	**MG**	Madagascar
AU	Australia	**FI**	Finland	**ML**	Mali
BB	Barbados	**FR**	France	**MN**	Mongolia
BE	Belgium	**GA**	Gabon	**MR**	Mauritania
BF	Burkina Faso	**GB**	United Kingdom	**MW**	Malawi
BG	Bulgaria	**GN**	Guinea	**NL**	Netherlands
BJ	Benin	**GR**	Greece	**NO**	Norway
BR	Brazil	**HU**	Hungary	**PL**	Poland
CA	Canada	**IT**	Italy	**RO**	Romania
CF	Central African Republic	**JP**	Japan	**SD**	Sudan
CG	Congo	**KP**	Democratic People's Republic of Korea	**SE**	Sweden
CH	Switzerland			**SN**	Senegal
CI	Côte d'Ivoire	**KR**	Republic of Korea	**SU**	Soviet Union
CM	Cameroon	**LI**	Liechtenstein	**TD**	Chad
CS	Czechoslovakia	**LK**	Sri Lanka	**TG**	Togo
DE	Germany	**LU**	Luxembourg	**US**	United States of America
DK	Denmark	**MC**	Monaco		

METHOD AND APPARATUS FOR NUCLEAR FUSION

Technical Field

The present invention relates to a method and apparatus for nuclear fusion of species in electrolytes at overall low temperatures, wherein low temperature refers to a temperature significantly below that of the plasma temperature in presently known thermonuclear reactors. More particularly, the invention relates to the fusion of particles that have been accelerated by local electromagnetic fields in a migrational transport layer. The invention allows for the regulated liberation of nuclear energy by controlling and sustaining the stability and rate of all reactions during long periods of operation.

Background Art

On March 23, 1989, Martin Fleishmann and Stanley Pons announced the discovery of cold fusion of deuterium in a galvanostatic process using 0.1M LiOD in 99.5% D_2O + 0.5% H_2O solutions, palladium cathodes, and platinum anodes ("Electrochemically Induced Nuclear Fusion of Deuterium," J. Electroanalytical Chem., 261:301-308 (1989)). The investigators used sheet, rod and cube-shaped cathodes and varied the cathode size and current density during their experiments. Based on calorimetric measurements, analyses of gamma-ray spectra, and measurements of tritium generation/accumulation, it was concluded that cold nuclear fusion occurs in such galvanostatic processes. Moreover, it was suggested that the energy released in the process may exceed that consumed by the electrolysis, and, thus, a fusion method might be developed as a practical source of energy.

Within a few weeks after this announcement, the existence of cold fusion was evaluated by several

laboratories in the United States and other countries. For instance, Steven Jones at Brigham Young University used a "pressure-loading" technique to saturate a metal with gaseous deuterium using high pressure. The generation of neutrons in "pressure-loading" experiments has been taken as evidence of cold fusion. Although scientists agree that cold fusion does occur, many scientists state that it is a question of probabilities, meaning that the probability of fusion must be very high in order for the process to become a commercially viable source of energy. Unfortunately, the energy yield and levels of efficiency reported by Fleishmann and Pons were not achieved by other researchers. Moreover, many researchers were unable to reproduce the Fleishmann/Pons experiments.

Currently, all scientists involved in cold fusion research attribute the fusion effect to the accumulation of deuterium within a metal matrix, hypothesizing that the Coulomb repulsion barriers between deuterium nuclei are reduced and the probability of effective collisions increased. However, reasons for reduced potential barriers are not understood. As Fleishmann and Pons state in J. Electroanalytical Chem., 261:301-308 (1989): "the results reported here raise more questions than they provide answers, and . . . much further work is required on this topic. The observation of the generation of neutrons and of tritium from electrochemically compressed D^+ in a Pd cathode is in itself a very surprising result and, evidently, it is necessary to reconsider the quantum mechanics of electrons and deuterons in such host lattices."

It is suggested herein that the major problem associated with the previously demonstrated cold fusion phenomena is that it has been assumed to happen in the metallic lattice of the body of the metal. Particularly,

Fleishmann and Pons state that the efficiency of the process increases when large volume palladium electrodes are used. This questionable hypothesis leads to irreproducible results and, thus, to uncontrollable cold fusion processes. Therefore, there exists a need for a method and apparatus that provides for controlled cold nuclear fusion.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for cold nuclear fusion in which fusionable particles located within an electrolyte are accelerated by local electromagnetic fields in a migrational transport layer. This migrational transport layer can be induced either by creating a cementation system, applying an outside source of current to an electrode system, or a combination of both. The intensity of the local electromagnetic fields can be controlled in various ways such as adding promoters, indifferent ions, complexing agents, or anions to the electrolyte; optimizing the mixing rate of the electrolyte; or controlling the temperature of the electrolyte.

Accordingly, it is an object of the present invention to provide a method of predictable, sustainable, and controllable cold nuclear fusion. Another objective of the present invention is to provide a method of cold fusion wherein specific induction means are used for controlling the fusion rate, yield and efficiency. Yet another objective is to reduce process costs by using metals such as iron, aluminum, zinc, magnesium, etc. instead of platinum, palladium, or other expensive metals and alloys.

Furthermore, it is an object of this invention to provide for cold nuclear fusion in which fusionable

particles located within an electrolyte are accelerated by local electromagnetic fields in a migrational transport layer. This migrational transport layer may be induced by the creation of a cementation system, the application of current from an outside source, or both.

More particularly, it is an object of the present invention to provide a method and apparatus for cold nuclear fusion in which a migrational transport layer is induced by submerging a sacrificial metal in an electrolyte that contains heavy water and a salt of a second metal that is more noble than the sacrificial metal. A further object of this invention is to increase the surface area of the cathode by connecting a cathodic material more noble than the sacrificial metal to the sacrificial metal. A still further object of this invention is to submerge the sacrificial metal and the connected cathodic material in separate compartments such that the sacrificial metal is submerged in a cementation electrolyte and the cathodic material is submerged in an electrolyte containing heavy water.

Furthermore, it is an object of the present invention to provide a method and apparatus for cold nuclear fusion in which an electrolyte containing heavy water is brought into contact with an electrode system having at least one anode and at least one cathode and a migrational transport layer is induced by applying a high current density to a cathode. The current can be applied as direct current pulses. A further object of this invention is to increase the intensity of the local electromagnetic fields by applying a polarizing current to the electrode system to dialyze the electrolyte.

These and other objects and advantages of the present invention are apparent to a person skilled in the art from the following detailed description.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is an illustration of the migrational mechanism of cementation processes;

Fig. 2 is an illustration of the electrode processes and transformations occurring at anodic sites in cementation systems;

Fig. 3 is an illustration of the electrode processes and transformations occurring at the cathodic sites in cementation systems operated in migrational regimes;

Fig. 4 is a graphic representation of the potentials and distributions of major ionic species in the galvanic cell;

Fig. 5 is a graphic representation of distributions of anions and cations at the anodic sites;

Fig. 6 is a current-potential diagram of the cementation system;

Fig. 7 is an equivalent electric circuit of cementation processes;

Fig. 8 is a cross-section of a batch reactor for cementation induced nuclear fusion processes;

Fig. 9 is a cross-section of a flow through reactor for cementation induced nuclear fusion processes;

Fig. 10 is a cross-section of a cementation reactor for nuclear fusion with a composite electrode made

of interconnected sacrificial metal and a noble cathodic metal;

Fig. 11 is a cross-section of a flow through noble metallic cathode for pulsing noble metal salts in the course of reinduction of migrational regimes;

Fig. 12 is a cross-section of a reactor for cementation induced nuclear fusion process with separate cementation and fusion zones;

Fig. 13 is a cross-section of a reactor for nuclear fusion process driven by an external source of electricity;

Fig. 14 is an illustration of a fluidized bed reactor for the cementation induced nuclear fusion reaction;

Fig. 15 is a cross-section of a membrane reactor for the electrochemically driven nuclear fusion reaction.

Fig. 16 is a cross-section of an alternative embodiment of a membrane reactor for the electrochemically driven nuclear fusion reaction.

DETAILED DESCRIPTION OF THE INVENTION

This invention relates to a method and apparatus for producing and controlling cold nuclear fusion in a migrational transport layer formed off the surface of a metal in an electrochemical system. The following subsections describe the formation mechanism, statics, and dynamics of a migrational transport layer in an electrochemical system; the nuclear fusion processes that occur in such a layer; the variables that control the layer; and preferred embodiments utilizing the layer.

As used herein, the term "promoter" refers to negatively charged ions or neutral species capable of being reduced at the cathode. Examples of promoters include, but are not limited to, $Cr_2O_7^{2-}$ and VO_4^{3-}. The term "indifferent ion" refers to an ion that does not participate in reactions at either the cathode or anode. Examples of indifferent ions include, but are not limited to, Li^+, Na^+, and K^+. A "complexing agent" refers to a mineral or organic species that can complex with a metal to slow down the metal's rate of diffusion. Examples of complexing agents include, but are not limited to, Cl^-, NH_3, CN^-, and EDTA. "Heavy water" refers to water in which hydrogen nuclei are replaced by deuterium and/or tritium nuclei; "common water" refers to water that does not contain deuterium and/or tritium nuclei. "Noble metal species" or "noble species", "noble metal particles," or "noble particles", and "noble metal ions"or "noble ions" refer to metal species, particles and ions, respectively, that are electropositive relative to another metal, usually referred to as the "sacrificial" or electronegative metal. Examples of noble species can include, but are not limited to, Cu^{2+}, Ag^+, Hg^+, Cd^{2+}, or $Cr_2O_7^{2-}$. The term "cementation electrolyte" refers to an electrolyte that contains at least one noble species. The term "filament" is meant to refer to a protrusion of any shape that ends in a relatively sharp point.

1. <u>The Migrational Transport Layer and Related Electrode Processes</u>.

As described in Boris Mikhail Khudenko, "Mathematical Models of Cementation Processes", <u>Proc. Env. Eng. Div., Amer. Soc. Civil Eng.</u>, 113:681-701 (1987), two possible mechanisms for transferring species across the boundary layer at cathodic sites are possible: diffusional and migrational. When the species participating in electrochemical processes are transported

by diffusion, all cathodic reactions occur at the surface of the cathodic sites, or, in accordance with conventional models, within the adsorption layer at this surface.

A schematic showing the electrochemical reactions occurring during the migrational transport of species is illustrated in Fig. 1. Because the properties of metal surfaces are nonuniform, multiple electrolytic (cathode C_e and anode A_e) and galvanic (anode A_g and cathode C_g) cells are spontaneously induced. A cell is termed "electrolytic" based upon the original cementation process objective of reducing noble species through electrolysis. Cells that do not reduce noble species through electrolysis are referred to as galvanic cells. Electrolytic cells include anodic sites A_e, a boundary layer B_e at anodic sites A_e, the bulk solution, and cathodes C_e, located opposite the cathodic sites C_g on the sacrificial metal surface. Galvanic cells are comprised of cathodic sites C_g, a migration layer δ_g, and anodes A_g adjacent to cathodes C_e. Anodes A_g and cathodes C_e are associated with primary particles marked in Fig. 1 by the symbol $\Sigma Me_{(2)}$. $Me_{(1)}$ refers to sacrificial metal species and $Me_{(2)}$ refers to noble metal species.

Typically, the bulk solution contains noble ions, either cations $Me_{(2)}^{m+}$, such as Cu^{2+}, Ag^{+}, noble metal containing anions, such as $Cr_2O_7^{2-}$, or other electron accepting species; acids, such as H_2SO_4 or HCl, or alkalies for pH control; and indifferent ions I^{s+}, An^{r-}, which do not participate in electrode reactions. Complexing agents, for example cyanides, may also be used.

Electrode processes and transformations occurring at the anodic sites A_e of Fig. 1 in electrolytic cells are illustrated in Fig. 2, using univalent anions and a divalent sacrificial metal as an example. These processes and transformations involve the following: (1)

adsorption of anions An^{r-} from the bulk solution on the surface of sacrificial metal $Me_{(1)}$; (2) formation of a salt and liberation of electrons that flow to cathodes C_g in galvanic cells; (3) dissolution and (4) dissociation of salt molecules. Dissolved metal cations remain in the bulk solution while the anions may return to the anodes A_g.

Transformations at the cathodic sites, electrodes C_g, A_g, and C_e of Fig. 1, involve the following steps as shown in Fig. 3: (1) acceptance of an electron by hydrogen ion and the consequential formation of adsorbed atomic hydrogen H_{ad}, (2) diffusion of the atomic hydrogen into the body of the sacrificial metal to produce H_{ab}, the resulting association with electroconducting electrons to form hydride ion, H^-, and the ejection of a negative particle (a hydride ion) from cathodes C_g as shown in Fig. 1; (3) transportation of hydride ions in the boundary layer and reaction with noble species, which results in the formation of reduced products and in the recovery of hydrogen ions; and (4) a side reaction between hydride and hydrogen ions to form molecular hydrogen. The H^+ and H^- species constitute specific hydrogen electrodes ($H^+ + 2e^- \rightarrow H^-$ and $H^- \rightarrow H^+ + 2e^-$) which differ from the standard hydrogen electrode ($2H^+ + 2e^- \rightarrow H_2$). Hydride ions may be transported in accordance with a relay mechanism in which weakly bound electrons jump from one proton to another. A similar relay mechanism has been described for the transport of hydronium ions H_3O^+ in electric fields. Depending on the transportation mode, the transformations at the cathodic sites shown in Figs. 1 and 3 may be spatially separated, or may occur at the sacrificial metal surface.

At the initiation or spontaneous induction of cementation, an electrical double layer is formed at cathodic sites. The outer Helmholtz layer is comprised of

hydrogen ions, noble cations, and indifferent ions such as Na^+. As a result of the interaction between hydrogen ions and electrons, hydride ions are emitted from cathodic sites, while noble ions diffuse from the bulk solution towards the cathodic sites. Thus, two opposite fluxes are formed: a hydride flux and a counterflux of noble ions. The species in these fluxes react with each other ($H^- + Me^{2+} \rightarrow H^+ + Me$).

At the onset of the cementation process, either the hydride flux or the noble cation flux is greater. In the former case, the reaction between ions in these fluxes results in the disappearance of noble ions from the layer adjacent to the cathodic sites and the reaction front moves to a distance δ from the cathodic sites where these fluxes are equal (see Figs. 1 and 4b). In this case, electrodes A_g and C_e would form at the reaction front. The initial potential determining processes at these electrodes and at the cathodic sites C_g are shown in Fig. 1. The hydrogen ions recovered at the electrode A_g create a flow across the δ_g layer and counterfluxes of H^+ and H^- ions in this layer create an electrical current, thus constituting the migrational transport of species at cathodic sites.

In the latter case, in which the diffusion flux of noble species is greater than the flux of hydride, the reaction front is shifted towards the cathodic sites. Transitional regimes between these two situations are theoretically possible when initial hydride and noble ions fluxes are nearly equal; however, such regimes are not likely to be stable.

The main reactions at electrodes C_g and A_g are $H^+ + 2e^- \rightarrow H^-$ and $H^- \rightarrow H^+ + 2e^-$, respectively. The equilibrium potentials (volts) that are thermodynamically possible at these electrodes are given by $E = -1.125 + RT/2F$

$\ln[H^+]/[H^-]$. Because the same species, hydrogen and hydride ions, constitute both cathode C_g and anode A_g, the galvanic cell is a concentration element. Additionally, hydrogen ions disappear at C_g, while hydride ions completely disappear because of fast electrode reactions at A_g.

2. Statics of the Migrational Transport Layer.

Although the cementation process is essentially dynamic, a discussion of the statics of the process is necessary to establish a framework to describe the process dynamics. First, Ohm's law can be applied to the electric current within the δ_g layer, giving rise to a potential gradient. Under the influence of this potential gradient, cationic species that approach the electrode A_g by convection in the bulk solution will be pumped into the migration layer (δ_g), whereas anionic species will be pumped out of this layer (with the exception of noble and hydrogen species which disappear at the A_g electrode).

Under this pumping effect, an accumulation of hydrogen, H^+, and indifferent cations such as Na^+ occurs in the layer δ_g. Accordingly, a considerable concentration gradient and diffusional backflow of these ions takes place, and, therefore, the velocity of hydrogen ions in the electrical field decreases. In contrast, hydride (or relayed electrons) will be pumped out of the δ_g layer under the influence of both the electrical forces and diffusional phenomena. A graphic presentation of relative potentials and distributions of ionic species in the galvanic cell for a static case is given in Fig. 4. Solid lines in Fig. 4 are related to a single noble specie, while broken lines illustrate the effects of multiple (two) noble species; δ and δ' refer to the distance of the reaction front edge of the migrational layer δ_g from cathodes C_g when a single noble specie and multiple noble

species are present, respectively. DL refers to the electrical double layer present at the electrodes.

Indifferent cations I^+ do not take part in the electrode reactions in the galvanic cell. Accordingly, they accumulate within the galvanic cell and are distributed across the cell as shown in Fig. 4c; these ions migrate towards the electrode C_g under the force of the electric field and flow back because of diffusional effects. These phenomena, and the resulting distribution of ions, are analogous to the sedimentation-diffusion equilibrium for colloidal particles in liquids. A small quantity of indifferent ions diffuses out from the δ_g layer. The resultant gradual drop in concentration of indifferent ions at the outer border of the δ_g layer is also shown in Fig. 4c.

The distribution of hydrogen ions (Fig. 4d) is similar to that of indifferent ions. However, because H_3O^+ possesses an exceptionally high electric mobility and, thus, a higher ratio of electric to diffusional forces, the distribution of hydrogen pumped into the δ_g layer is characterized by a steeper curve, reflecting a greater proportion of hydrogen ions as compared to indifferent ions in the vicinity of electrodes C_g. As with indifferent ions, hydrogen ions leak out of the δ_g layer because of diffusion. In contrast to indifferent ions, however, hydrogen ions react at the electrode C_g to form hydride ions.

Hydride ions (or electrons originating from hydride ions) are ejected from the electrode C_g and are further repulsed from the δ_g layer under electrostatic forces as shown in Fig. 4e. Anions (Fig. 4f) are also pumped out of the δ_g layer.

When two or more different noble ions are used, a synergistic effect on the process rate may occur. Such an effect can be attributed to the following three factors: different reduction potentials, different diffusivity, and different ion charge (either plus or minus). These three factors effect the individual thickness of the δ_g layer for a given noble specie. An analogous phenomenon was described by Levich in Physicochemical Hydrodynamics, Prentice Hall, 1962, in relation to diffusion in various mass transfer processes. Fig. 4 illustrates the distributions of potentials and concentrations of reacting and indifferent species for two noble species (broken and solid lines). The width of the migration layers for these species are δ'_g and δ_g, respectively. It follows from Fig. 4 that the potentials and concentrations at point δ' change stepwise and the average potential gradient becomes steeper when two noble species are reduced as compared to a single specie. Accordingly, both species may be reduced faster than either of them taken individually. A combination of noble species can be used to induce, accelerate, or reinduce the migrational cementation regime. Some noble species, particularly negatively charged ions such as $Cr_2O_7^{2-}$ or reducible electrically neutral species, may be used as promoters of the migrational cementation regime.

Considering the effect of cations being pumped into and anions pumped out of the δ_g layer, the electrolyte within the galvanic cell is positively charged. However, the bulk solution remains electroneutral. For the overall system to remain electroneutral, therefore, a quantity of anions equivalent to the excess hydrogen and indifferent cations accumulated in the galvanic cell must accumulate at anodic sites A_e. These accumulated anions "push" and the hydrogen and indifferent cations "pull" the electrons in the sacrificial metal, giving rise to the so-called push-pull mechanism.

Anions are electrostatically attracted to the anodic sites A_e and diffuse in the opposite direction. Cations at anodic sites, including those that originated from the dissolution of the sacrificial metal, are repulsed from the anodic sites under the action of electrostatic forces. The distributions of anions and cations at anodic sites are illustrated in Figs. 5a and 5b.

Once established, the reservoirs of positive and negative charges at the cathodic and anodic sites, respectively, will not change substantially during the course of the process because of a mutual attraction through the body of a metal. Thus, a virtually constant push-pull tension and a virtually constant potential difference, averaged over long time intervals, is created. Slow relaxation of these charge reservoirs may occur from the diffusional leakage of anions and cations from boundary layers at anodes and cathodes, respectively. For example, such leakage may occur when the jump in the electric potential at the outer border of the δ_g layer decreases upon the depletion of noble species in a batch process.

The electric current in the system flows from the electrode A_e to the electrode C_g (flow of electrons), from C_g to A_g (flow of hydride ions, or electrons, and electrical-diffusional motion of hydrogen and indifferent ions), from A_g to C_e (electrons), and from C_e to A_e (current in a binary electrolyte in the bulk solution, electrical-diffusional flow of anions, and predominantly electrical flow of sacrificial cations in the boundary layer at anodic sites). Electrodes A_e and C_g, as well as A_g and C_e, are short-circuited by the sacrificial metal and the primary particles respectively. Accordingly, these pairs of electrodes have the same potentials a and b as shown in

Fig. 6, which illustrates an instantaneous potential-current diagram for the migrational cementation regime. The diagram is a plot of log i versus E, in which i_a and i_c are anodic and cathodic currents, respectively, and E is the potential. Evaluation of the magnitude of the potential difference, U = a - b, across the δ_g layer and across the bulk solution and the boundary layer at anodic sites will be given later. The value of U reflects the magnitude of the tension produced through the push-pull effect.

Anodic and cathodic sites arise because of defects in the lattice structure on the surface of sacrificial metal. When a single pair of anodic-cathodic sites occurs, it induces multiple sites on the entire surface of the sacrificial metal exposed to the electrolyte. Moreover, the electrical fields in all pairs of cells are basically identical. For example, a sacrificial metal may be a clump of twisted wire. The electrical cells inside and outside the clump will have similar characteristics. However, the fields developed at sharp edges will be stronger.

Electrical cells will also be induced across a membrane having a cementation electrolyte on one side and an electrolyte lacking noble species on the other side. Processes other than the reduction of a noble species may be performed on the "opposite" side of the membrane. Sacrificial metal can be attached to a more noble metal, which becomes polarized cathodically. Thus, galvanic cells are induced on the surface of the more noble metal.

The positive charge within the δ_g layer caused by hydrogen ions is not conserved because hydrogen ions take part in electrode reactions and disappear from this layer. For example, H^+ reacts to form molecular hydrogen when noble ions become depleted. Accordingly, the relaxation

of the positive charges, and thus the negative charges, would occur rapidly. However, this relaxation can be slowed when indifferent ions are present in the electrolyte because they constitute a fraction of the positive charge in the δ_g layer. Moreover, when hydrogen ions disappear from the δ_g layer, they are substituted by indifferent ions. Thus, two properties of indifferent ions are important: electrical mobility and diffusivitiy. An optimal relationship between mobility and diffusivity can be achieved by using a mixture of various indifferent ions such as Li^+, Na^+, K^+, etc.

3. Dynamics of the Process.

The migrational layer δ_g and the layer at anodic sites can be analogized to capacitors. Considering that reduction of noble species and oxidation of sacrificial metal result in the production of electrical energy, the electrochemical system comprised of anodes A_e, cathodes C_e, and the associated electrolyte can be considered as a generator of electricity. It is also suggested herein that the electric current across the δ_g layer occurs in repeated pulses, each pulse similar to a break down current in a capacitor. This current is triggered by the accumulation of electric charges in the capacitor and the subsequent deformation in the distribution of cations in the δ_g layer. During flow of the break down current, the δ_g layer can be considered as an inductance. After each pulse, the distribution of cations within the δ_g layer becomes more uniform and the layer becomes a capacitor again. The overall system also has some active resistances.

Fig. 7 shows an equivalent electrical circuit which reflects a number of major processes in the overall system. In Fig. 7, capacitor C_1 corresponds to the δ_g layer, L_1 is the inductance, K is a trigger, R is an active

resistance, G is a generator and C_2 is a capacitor at the anode A_e. The sacrificial metal and the outer border of the δ_g layer are electric conductors.

The plates of the capacitor C_1 are formed by cathodes C_g and the outer border of the δ_g layer containing primary particles and noble species. Aqueous indifferent cations and hydrogen ions constitute a specific dielectric between plates. The polarization of such a dielectric is determined by the balance of electrostatic and diffusional forces acting upon these cations. The electrostatic forces provide order, while diffusional forces produce disorder in the dielectric. Taken over a short period of time (the duration of the charging period), mobile cations prevent the break down of the capacitor C_1 and, thus, substantial charges and a voltage differential arise in the capacitor C_1.

The capacitor becomes charged by the above-described pumping and push-pull mechanisms. When the potential difference between the capacitor's plates reaches the break down voltage, electric current flows between the plates. The break down current occurs in the form of short-lived streamers, forming a tunnel of positively charged particles that are present in the δ_g layer because of the pumping and push-pull effects (indifferent and hydrogen cations) with negative particles (electrons that originated from hydride ions) forming the core of the streamer. Because streamers are short-lived, the break down current changes very rapidly. Accordingly, this current induces very strong electromagnetic fields and the streamers can be considered as inductance L_1 in the overall electric circuit.

Streamer formation is facilitated by the non-uniformity of the electric field in the δ_g layer (capacitor C_1). This non-uniformity, in turn, can be attributed to

rough deposits of noble metal on the surface of cathodic sites C_g and discontinuities in the outer border of the δ_g layer where discrete minute primary particles and noble ions are located. The electric field is strongest between deposit protrusions and the discrete points in the outer border of the δ_g layer. Accordingly, cations migrate towards a line connecting these protrusions and discrete points, forming the streamer's shell and attracting electrons into the core of the streamer. Once a streamer is formed (corresponding to closing the trigger K in Fig. 7), a rapidly changing pulsed current occurs. This current produces a strong electromagnetic field, which causes the cross-section (diameter) of the streamer to contract and, thus, the streamer's body becomes momentarily separated from the surrounding water. Accordingly, the plasma in the streamer is in a vacuum and, therefore, no energy is lost to the surrounding media on the sidewall (shell) of the streamer.

In the electric field in the specific dielectric within the δ_g layer, electrons and cations are accelerated; electrons move towards the outer border of the δ_g layer, while cations move towards cathodes C_g. A relay motion of electrons surrounded by cations of hydrogen in streamers occurs from cation to cation and the overall electron motion can be considered as equivalent to the transport of hydride ions originally formed at cathodes C_g. Electrons react with noble species at the outer border of the δ_g layer.

When trigger K is on (break down of capacitor C_1) and rapidly varying electric current is flowing through inductance L_1, a strong electromagnetic field is induced, resulting in a current that charges the capacitor C_2. Physically, this corresponds to pushing electrons from and attracting anions to the anodic sites A_e.

After capacitor C_1 is discharged, the current through inductance L_1 is interrupted, which corresponds to trigger K being turned off. The capacitor C_1 then becomes charged from capacitor C_2 and the cycle is repeated.

This electric circuit is a typical resonant circuit, which produces resonances in the electric tension and currents. Considering that the losses caused by the active resistance are completely compensated by the energy generated in the electrochemical processes and the frequency of the energy generator G completely coincides with the natural frequency of the resonant circuit, amplification of the electric tension and the electric currents must be very large.

Referring to Fig. 6, the value of potential difference U can be considered as the potential difference induced in the resonant circuit. Considering the process dynamics, the phases of U for capacitors C_2 and C_1 (or inductance L_1) are opposite, while the phase of the electric current and the tension for inductance L_1 (capacitor C_1) are slightly shifted. The discharge in the galvanic cell becomes a high-voltage, high-current pulsed discharge and, therefore, a high power discharge. The magnitude of the voltage difference U can be estimated as follows: the estimated width of the δ_g layer ranges from 0.01 to 0.1 cm and the specific break through voltage is of the order of magnitude 10^6 V/cm; hence, the value of U may range from 10 to 100 kV.

Referring to Figs. 4, 5, and 6, the distribution of species and potentials, as well as the electrode currents, should be taken as instantaneous pictures of a dynamic process. All these values change very rapidly. Moreover, the phases of these changes are either opposite or slightly shifted as described above.

When heavy water, or a mixture of common and heavy water, is used in a cementation reactor, both deuterium, D^+ (tritium, T^+ if added) and hydrogen, H^+, ions participate in electrode reactions to form hydride, H^-, and deuteride, D^- (T^- if added). Deuterium ions D^+ (T^+) will also take part in the formation of streamers and will be involved in the current across the δ_g layer. Physically, they will be accelerated towards the cathode C_g on the surface of the sacrificial metal.

Collisions of accelerated hydrogen, deuterium, and tritium particles may trigger the following possible nuclear reactions:

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2D + {}_1^0e + {}_0^0 \qquad (1) $$

$$ {}_1^1H + {}_0^1n \rightarrow {}_1^2D + \qquad (2) $$

$$ {}_1^2D + {}_1^1H \rightarrow {}_2^3He + \qquad (3) $$

$$ {}_1^2D + {}_1^2D \rightarrow {}_1^1H + {}_1^3T \qquad (4) $$

$$ {}_1^2D + {}_1^2D \rightarrow {}_2^4He^* \qquad (5a) $$

$$ {}_2^4He^* \rightarrow {}_2^3He + {}_0^1n \qquad (5b) $$

$$ {}_1^2D + {}_1^2D \rightarrow {}_2^3He + {}_0^1n \qquad (6) $$

$$ {}_1^2D + {}_1^3T \rightarrow {}_2^4He + {}_0^1n \qquad (7) $$

$$ {}_1^2D + {}_2^3He \rightarrow {}_2^4He + {}_1^1H \qquad (8) $$

$$ 2\,{}_2^3He \rightarrow {}_2^4He + 2\,{}_1^1H \qquad (9) $$

A substantial amount of energy would be liberated in these reactions. The most probable reactions are (3), (4), (5a)/(5b) or (6), and (7). The most preferred reaction

would be (5a) followed by deexitation of $^4_2He^*$. Such a reaction would produce 23.8 MeV of energy per collision and, considering the deexitation, an innocuous final product - a stable helium atom. The deexitation can be achieved through an internal conversion mechanism in which the exited state energy is transferred to electrons and gamma rays are not produced. Protons are also not generated in reaction (5a).

Collisions resulting in fusion reactions may occur along the length of streamers within the δ_g layer. The probability of inelastic collisions is greater at the cathodic sites at which hydride ions are emitted in a direction opposite to the oncoming positive hydrogen or deuterium ions. Also, it is more probable that deexitation of $^4_2He^*$ can occur at the cathodic sites because the energy of the exited state can be transferred to electrons in the hydride ions, the sacrificial metal, or the metallic deposits.

Thus, in accordance with the description presented herein, the essential element of the method includes the induction of the migrational layer δ_g, within which H^+ and H^- (or D^+ and D^-) ions and electrons originating from H^- (or D^-) are accelerated in a very strong local electrical field. As previously described, such a layer can be induced in cementation systems. Induction of such a layer can be further promoted by the use of promoters, such as negatively charged reducible noble ions (for example, $Cr_2O_7^{2-}$).

In addition, the cathodic area can be increased by using a cathode composed of a metal more noble than the sacrificial metal such that these two metals are connected and attached to each other and submerged in a solution of a noble metal salt. A further modification includes electrically connecting the sacrificial and noble metals

and submerging them in separate vessels; the sacrificial metal is submerged in a solution in which it becomes anodically dissolved (for example, an acid), while the more noble cathodic metal is submerged in a solution of a salt of a noble metal. Metals included in this salt should not necessarily be the same metal as the cathodic metal. For example, the sacrificial metal can be zinc, the noble cathodic metal may be platinum, and the noble metal of a dissolved salt may be copper. Other combinations of metals are also possible.

Also, a cathodic noble metal can form a membrane that separates the vessel (or compartment) for dissolving the sacrificial metal from the vessel (or compartment) for the cementation of the noble metal contained in the dissolved salt onto the cathodic noble metal. Moreover, the membrane may also be made of the sacrificial metal. If so, however, the sacrificial metal membrane would eventually dissolve. When heavy water is used in the vessel (or the compartment) containing the solution of the noble metal salt, the nuclear reactions listed above would also take place.

Alternatively, the migrational layer δ_g, with all properties as described above for cementation systems, can be induced by applying high current densities in electrolytic baths operated at moderate mixing levels and low to moderate concentrations of noble metals (or metals being plated). For example, in electrolytic baths for plating (or refining) various metals, powdery metals are sometimes formed. The regimes at which powdery metals are formed correspond to the induction of the migrational layer at localized cathode areas. The induction of such localized areas is encouraged by the use of nonsmooth cathodes. Accordingly, the use of cathodes formed from mesh and various ridge, valley, and other shapes having

protrusions promotes the induction of localized migrational zones at the cathode surface.

A process in a reactor with electrodes to which a pulsed current is applied from an external source can be used. In this process, the pulsed current induces the migrational layer and, thus, emulates the cementation process.

The effectiveness and the rate of cementation processes in migrational regimes, whether induced by cementation or by applying high current densities, depend upon the magnitude and the density of hydride-hydrogen fluxes in the δ_g layer; greater hydride-hydrogen fluxes result in greater cementation rates. As described previously, hydrogen and hydride ion fluxes are induced to match (to equal approximately) the original diffusional flux of noble species that occurs at the time the migrational layer is induced. An optimal concentration of noble species can be used at the induction period only to produce the maximal hydrogen-hydride fluxes. Thereafter, a lower, or greater, concentration of noble ions would not change the fluxes and the maximum process rate could be maintained for a substantial period of time. Periodically, reinduction of optimum fluxes may be needed because of relaxation processes. Such reinduction can be performed by using hollow, perforated, or porous electrodes (such as those made by the use of metal powder fusing) with periodic injection of a noble salt solution having an optimal concentration of noble metals.

Alternatively, the process rate may be increased by employing fluidized electrodes made of sacrificial metal particles, chemically neutral particles such as gold or platinum, or particles of the same metal as the noble cations, for example, copper, silver, etc. In the latter case, particles formed in cementation processes (cement

powders) are preferred. Chemically neutral particles and particles of the same metal as the noble cations can be added to either a cementation system or to an electrically driven system. In nuclear processes, the improved heat transfer in the fluidized electrode system would be an additional advantage.

A combination of a cementation and electrically driven process can also be possible in which the migrational layer is induced by a cementation mechanism followed by cathodic polarization of the sacrificial metal, thus making the sacrificial metal behave as a more noble metal. In this process, consumption of sacrificial metal would be reduced. Additionally, the optimal concentration of the noble metal species can be provided only during the induction period, reducing the consumption of noble metal salts.

A reducing atmosphere eliminates the retarding effect of oxygen at the cathodic sites, in which oxygen oxidizes hydrogen ions and reduces the effective flux of hydrogen species. A reducing atmosphere can be provided by bubbling H_2 or D_2 gases, or a mixture of these gases, into the electrolyte. The use of a neutral atmosphere, such as N_2 gas, also reduces the negative effect of oxygen.

The sacrificial metal or electrodes can be formed from Zn, Mg, Ca, Al, Fe, Ni, Co, and other inexpensive or moderately expensive metals or alloys. Unlike the known process, no substantial pumping of hydride into the entire volume of the body of the metal used for cathodes, or having cathodic sites, is necessary, because the reactions of interest occur not in the body of the electrode (cathode), but in the liquid in the migrational layer.

4. Control Variables.

The cementation rate in the migrational regime can be controlled by an appropriate selection of noble species, singly or in mixtures; optimal concentrations of noble species, singly or in mixtures; optimal pH; optimal selection of indifferent ions, singly or in mixtures; optimal concentrations of indifferent ions, singly or in mixtures; optimal selection of anions, singly or in mixtures; optimal concentrations of anions, singly or in mixtures; optimal selection and concentrations of complexing agents; optimal mixing rate; a reducing atmosphere; and an optimal temperature. The effects associated with these factors are discussed above and in Khudenko, "Mathematical Models of Cementation Processes," Proc. Env. Eng. Div., Amer. Soc. Civil Eng., 113:681-701 (1987); Gould et al., "Examination of the Zinc Cementation of Cadmium in Aqueous Solutions," Water Science and Tech., Vol. 19, Rio (1987); and Khudenko et al., "Specifics of Cementation Processes for Metals Removal," Proc. of the 5th Int. Conf. on Advanced Wastewater Treatment and Reclamation, IAWPRC, Vol. 2, Cracow, Poland, (1989). Additionally, the H_2O:D_2O ratio may be varied from 0 to 1 to control the density of fusionable particles. As discussed above, external sources of electricity, or their combination with cementation procedures, can be used to control the process.

5. Preferred Embodiments.

The following embodiments illustrate various aspects of the invention, but are in no way intended to limit the scope thereof. Like reference numbers refer to like parts in the various Figures.

Fig. 8 shows a batch reactor for cementation induced nuclear fusion processes. The reactor consists of vessel 1 filled with electrolyte 2, comprised of a mixture

of H_2O, D_2O and a noble metal salt and, optionally, a reagent for pH correction. Sacrificial metal 3 and heat exchanger 4 are submerged in electrolyte 2. Cool heat conduit 5, which can transport water or other heat-exchanging means, is connected to one end of heat exchanger 4 and heated heat conduit 6 is connected to the other end of heat exchanger 4. Optional means 7, for example a sparger for introducing a reducing gas (such as H_2 or D_2) or an inert gas (such as N_2) or a mixer for mixing electrolyte 2 is inserted in electrolyte 2. A migrational cementation regime is induced from the presence of optimal concentrations of noble ions, optimal pH in electrolyte 2, and optimal mixing of electrolyte 2. This cementation process induces nuclear fusion reactions, which generate heat and increase the temperature of electrolyte 2. This heat is removed from the reactor through use of heat exchanger 4.

Fig. 9 illustrates a flow-through reactor for cementation induced nuclear fusion processes. In addition to the elements illustrated in Fig. 8, flow-through input conduit means 8 and flow-through output conduit means 9, for supplying electrolyte 2 to and withdrawing electrolyte 2 from reactor vessel 1, respectively, are provided. Optionally, electrolyte 2 can also be used as a primary heat carrier. In this case, heat exchanger 4 and conduits 5 and 6 can be eliminated. Optionally, electrolyte 2 that is removed from vessel 1 through flow-through output conduit means 9 can be treated by the use of chemical or physical-chemical means to restore its original composition and recycled back into the reactor vessel 1 via flow-through input conduit means 8.

Fig. 10 shows an alternative preferred embodiment of a cementation nuclear fusion reactor, wherein a composite electrode, comprised of sacrificial metal 3 connected to a more noble metal cathode 10, is

submerged in electrolyte 2. The noble metal cathode 10 increases the total cathodic area in the cementation system and, therefore, the total process rate, per reactor, can be increased. Optionally, cathode 10 is comprised of a flat metal, a wire mesh, or grooved or wafer shaped material. A more developed surface area and a greater roughness of noble metal cathode 10 further increases the total process rate.

Fig. 11 illustrates a flow-through alternative embodiment to noble metal cathode 10. This flow-through cathode 50 is comprised of a porous or otherwise liquid permeable (for example, perforated) body 11, within which cavity 12 is provided. Input conduit means 13 is provided for supplying a solution 15 for inducing the migrational regime of cementation and output conduit means 14 is provided for flushing the internal cavity 12 of accumulated deposits 16. Porous electrode 50 is designed for attachment to sacrificial metal 3 (see Fig. 10). Both are submerged in an electrolyte that does not contain noble metal ions. For example, a solution 15 of a second electrolyte containing noble ions is fed periodically or continuously into cavity 12 via input conduit means 13. Solution 15 passes through porous walls 11 of the electrode and exits into the reactor vessel 1. In the presence of these noble metal ions, cementation and, subsequently, nuclear fusion are induced. Cemented deposits 16 can be formed inside the electrode. Such deposits are periodically flushed out via output conduit means 14.

Fig. 12 is an alternative embodiment of a cementation induced nuclear fusion reactor in which the reactor vessel 1 is comprised of two compartments, a cementation compartment 17 and a nuclear fusion compartment 18. These compartments are separated by a wall or membrane 19. A noble metal cathode 10, which is

submerged in compartment 18, is electrically connected by conductor 25 to a sacrificial metal 3 submerged in a cementation electrolyte in compartment 17. Compartment 18 contains an electrolyte comprised of H_2O, D_2O, and noble metal ions. This configuration provides for induction of a cementation reaction at the surface of the sacrificial metal 3 in compartment 17. The noble metal cathode 10 becomes polarized via conductor 25 and the cementation induced nuclear fusion process is initiated in compartment 18. Optional addition of noble ions into compartment 18 can increase the process rate. Optionally, membrane 19 is comprised of noble metal and serves as electrode 10. In this case, conductor 25 is attached to membrane 19.

Fig. 13 illustrates yet another alternative of the preferred embodiment. This embodiment comprises a reactor vessel 1, which contains electrolyte solution 2 having noble metal ions and an optimal pH; a heat exchanger 4 with cool and heated heat conduits 5 and 6 for transporting the heat carrier; flow-through input and output conduit means 8 and 9 for providing the flow-through of electrolyte 2; cathode 20 and anode 21 connected to a source of electric current 22 by means of conductors 23 and 24. Optionally, cathode 20 is replaced by cathode 50, which is described in Fig. 11. In this case, electrolyte 2 does not necessarily contain noble ions; noble ions can be provided by feeding a cementation induction solution 15 through input conduit means 13 (see Fig. 11) into porous electrode 50 and withdrawing the deposits 16 from the internal cavity 12 of the electrode through output conduit means 14. Optionally, the source of electric current may generate a partially rectified current emulating the pulsing regime such as induced in cementation processes.

The embodiment shown in Fig. 13 provides for three modes of operation: (1) application of high current

density to the electrodes with and without noble metal ions being added to the electrolyte; (2) application of electric current to the electrodes and induction-periodic reinduction of the migrational cementation regime by the use of the porous electrode; and (3) induction and maintenance of the migrational regime by use of the partially rectified pulsed current. In the first operational mode, the migrational regime is induced by use of a high current density obtained by applying a high current to the total electrode surface. This effect is further amplified by the use of electrodes with rough surfaces, which promotes very high localized current densities. The migrational regime is further intensified by the use of noble metal ions in electrolyte 2. The migrational regime at cathode 20 induces nuclear reactions at this electrode with subsequent energy generation in form of heat. In the second operational alternative, a solution containing noble ions is periodically or continuously fed through the electrode 50, thus inducing a migrational regime at the electrode. In the third operational regime, pulsing current is applied to emulate the pulsing regime such as induced in cementation processes. Optionally counterpulses can be used. Counterpulsing depolarizes the cathode and establishes a boundary layer such as found in the migrational cementation regime. This operational regime can be further improved by adding noble ions to electrolyte 2, as well as the use of high current densities.

Fig. 14 shows an embodiment in which a fluidized electrode cementation process is used. The process is performed in a reactor vessel 1, fed with electrolyte 2 through flow-through input conduit means 8 located on the bottom of vessel 1. Electrolyte 2 is removed at the top of the vessel 1 via flow-through output conduit means 9. A heat exchanger 4, with cool heat and heated heat conduits 5 and 6, respectively, is submerged in

electrolyte 2. Electrolyte 2 is preferably recycled. The reactor vessel 1 is charged with particles of a sacrificial metal 26 (optionally, more noble metal particles 27 can also be added). In the course of operation, the migrational regime of cementation is induced at suspended sacrificial particles, thus inducing nuclear fusion reactions. Further improvement in the process can be achieved by adding more noble metal particles, which increase the effective cathodic area of the fluidized electrode and, therefore, increase the overall process rate. Noble metal particles can also be previously cemented materials.

Fig. 15 illustrates an embodiment in which the reactor vessel 1 is compartmentalized by a membrane and multiple electrodes and an external source of energy are employed. Reactor vessel 1 is separated by permeable membrane 30 into anolytic 40 and catholytic 41 compartments. In catholytic compartment 41, cathode 33 and an anode 32 are submerged in an electrolyte, whereas an additional anode 31 is submerged in the electrolyte in the anolytic compartment. A source of polarization current 34, preferably, direct current, is connected by leads 37 and 36 to electrodes 33 and 31, respectively. A source of a pulsed current 35 is connected by leads 38 and 39 to electrodes 33 and 32, respectively. A heat exchanger 4 is attached to the body of the reactor vessel 1 and the heat carrier is fed through cool heat conduit 5 and discharged via heated heat conduit 6. For continuous operation either the electrolyte flow-through feed conduit 8a and/or 8b and electrolyte flow-through discharge conduit 9a and/or 9b are provided. Membrane 30 may be either an electroneutral porous membrane or an ion exchange (permeable to anions) membrane. In the case in which flow-through feed conduit 8b is employed, a cation exchange membrane should be used.

Still referring to Fig. 15, an electrolyte, as previously described, is fed into either compartment 40 via conduit 8b or compartment 41 through conduit 8a. Under the action of the direct current from electrical source 34, cations (noble, if any, hydrogen/deuterium, and indifferent cations) concentrate in compartment 41, while anions accumulate in compartment 40. Under the action of the pulsed current from source 35, the electric gap between electrodes 32 and 33 periodically breaks down and the nuclear fusion reactions occur, thus liberating energy in the form of heat. This heat is evacuated via heat exchanger 4.

The system of compartments 40, 41 and heat exchanger 4, with membrane 30 and electrodes 31, 32, and 33 can be considered as a single cell; a total reactor can be comprised of multiple cells assembled in a reactor unit similarly to an electrodializer apparatus or a multiple plate filter press. Such a reactor unit may be provided with one or several sources of electric currents 34 and 35.

Electrodes 32 and 33 may be comprised of flat plates or be provided with multiple filaments 42 and 43, respectively. The filaments 42, 43 protrude from the surface of the electrodes such that filaments on each electrode are separated by small gaps and face filiments on the other electrode, as shown in Fig. 15, so that electric discharge occurs between the filaments 42 and 43. Fluidized metallic particles may also be introduced between electrodes 32 and 33 in order to facilitate the discharge current between these electrodes. Sources of pulsed currents are described by Frolkin and Popov in "Pulse Circuits", Mir Publishers, Moscow, 1986, and by Pentegov in "Fundamentals Of Charging Circuits For Energy Accumulators With Capacitors", Publishing House "Naukova Dumka", Kiev, 1982.

Fig. 16 shows an alternative embodiment of a reactor compartmentalized by a membrane. This system is comprised of a reactor vessel 1 with a permeable membrane 30 (either electroneutral, or ion exchange); anode 32 located in compartment 40 and having filaments 42 penetrating across membrane 30; cathode 33 with optional filaments 43; a source of polarization current 34, preferably, a direct current, connected to electrodes 32 and 33 by leads 36 and 37, respectively; and a source of a pulsed current 35 connected to electrodes 32 and 33 by leads 38 and 39, respectively. Similarly to the embodiment shown in Fig. 15, electrolyte flow-through feed conduit 8a and/or 8b and flow-through discharge conduit 9a and/or 9b are provided. A heat exchanger 4, with cool heat conduit 5 and heated heat conduit 6 for heat carrier transport, is attached to the wall of the reactor vessel 1.

Electrode 32 preferably should be made permeable, for example, as a perforated plate or a wire mesh. A small gap has to be provided between the filaments of the electrode 32 and the plate or filaments of the electrode 33. Cells comprised of compartments 40, 41 and heat exchanger 4 can be assembled in a multiple cell reactor vessel. The wall between the compartment 41 and the heat exchanger 4 can be used as an electrode 33.

The embodiments exemplified in Figs. 15 and 16 are operated in the same manner, with the difference being only in the arrangement of anodes: single anode 32 with filaments 42 penetrating across membrane 30 in Fig. 16 versus two anodes 31 and 32 located at both sides of the membrane 30 in Fig. 15.

In all described embodiments, inexpensive sacrificial metals, such as Zn, Mg, Ca, Al, Fe, etc. can

be used. Fe, Ni, Cd, Cu, Ag can be used as noble metal for cathodes 10 and 50 (in Figs. 10, 11, and 12), 20 (Fig. 13) or 27 (Fig. 14) . More expensive metals such as Au, Pt or Pd can also be used. However, there is no necessity to use Pd or Ti only. Noble metal ions can be obtained from ions of Cu, Pb, Hg, Ag, etc. or mixtures of these ions can be selected. The sacrificial metal should always be more electronegative than the noble metal for cathodes 10, 50, 20 or 27, while the nobility of the noble metal ions should be equal to or greater than that of the noble metal for cathodes. Reducible metal containing anions, for example, $Cr_2O_7^{2-}$ or others, preferably should be used as additional promoters for inducing a migrational regime at cathodes.

While the invention has been described in detail with particular reference to preferred embodiments thereof, it will be understood that variations and modifications can be effected within the spirit and scope of the invention as previously described and as defined by the claims. For example, various combinations of the described embodiments can be used, reactors can be operated under elevated pressure and/or temperature, and various external electrical circuits can be used to emulate cementation systems by inducing a migrational layer.

WHAT IS CLAIMED IS:

1. A method for cold nuclear fusion, which comprises the steps of:

a) contacting an electrolyte containing heavy water with at least one anode and at least one cathode; and

b) inducing a migrational transport layer at said cathode to provide a local electromagnetic field capable of accelerating fusionable nuclei contained in said electrolyte to effect said cold nuclear fusion.

2. The method of Claim 1, wherein said induction step comprises creating a cementation system.

3. The method of Claim 1, wherein said induction step comprises applying high current density from an external electric source to said at least one cathode.

4. The method of Claim 1, wherein said induction step comprises creating a cementation system and applying high current density from an external electric source to said cathode.

5. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by the addition an indifferent ion to said electrolyte.

6. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by the addition of a promoter capable of being reduced at said cathode.

7. The method of Claim 6, wherein said promoter is selected from the group consisting of $Cr_2O_7^{2-}$ and VO_4^{3-}.

8. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by the addition of a complexing agent to said electrolyte.

9. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by increasing the temperature of said electrolyte.

10. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by the addition of an anion to said electrolyte.

11. The method of Claim 1, wherein the intensity of said local electromagnetic field is increased by optimizing the mixing rate of said electrolyte.

12. The method of Claim 1, wherein said at least one cathode possesses a nonsmooth surface to increase the intensity of said local electromagnetic field.

13. The method of Claim 1, wherein said heavy water contains deuterium nuclei.

14. The method of Claim 1, wherein said heavy water contains tritium nuclei.

15. The method of Claim 1, wherein said electrolyte is comprised of said heavy water and common water such that the ratio of said heavy water to said common water is adjusted to control the rate of nuclear fusion.

16. The method of Claim 1, wherein said electrolyte comprises a mixture of noble metal ion species.

17. The method of Claim 1, wherein said electrolyte comprises a mixture of indifferent ions.

18. The method of Claim 1, wherein said electrolyte comprises a mixture of anions.

19. The method of Claim 1, wherein said steps are performed in the presence of a reducing atmosphere.

20. The method of Claim 1, further comprising the step of adding fluidized noble metal particles to said electrolyte.

21. The method of Claim 20, wherein said noble metal particles comprise cemented noble metal particles.

22. The method of Claim 1, which further comprises the step of adding noble ions continuously to said electrolyte.

23. The method of Claim 1, which further comprises the step of adding noble ions periodically to said electrolyte.

24. The method of Claim 1, wherein said at least one cathode is permeable to liquids.

25. The method of Claim 24, which further comprises the step of adding noble ions to said electrolyte by injection through said permeable cathode.

26. The method of Claim 2, wherein said electrode system comprises a sacrificial metal submerged in said electrolyte and said electrolyte comprises a salt of a second metal that is more noble than said sacrificial metal.

27. The method of Claim 26, wherein the surface area of said at least one cathode is increased by connecting a

cathodic material more noble than said sacrificial metal to said sacrificial metal.

28. The method of Claim 27, wherein said sacrificial metal and said cathodic material are submerged in separate compartments such that said sacrificial metal compartment contains a cementation electrolyte and said cathodic material compartment contains said electrolyte containing heavy water.

29. The method of Claim 28, wherein the solvent for said cementation electrolyte is common water.

30. The method of Claim 28, wherein said sacrificial metal compartment and said cathodic material compartment are separated by a membrane comprising said cathodic material.

31. The method of Claim 27, wherein said cathodic material is permeable to liquids.

32. The method of Claim 31, which further comprises the step of adding noble metal ions periodically by injection through said permeable cathodic material.

33. The method of Claim 31, which further comprises the step of adding noble metal ions continuously by injection through said permeable cathodic material.

34. The method of Claim 26, wherein said sacrificial metal comprises fluidized particles.

35. The method of Claim 3, wherein said external electric source is comprised of pulses of current.

36. The method of Claim 3, wherein said method is carried out in a compartmentalized reactor having a

catholytic and an anolytic compartment separated by a membrane and having said cathode and a first said anode in said catholytic compartment and a second said anode in said anolytic compartment, which further comprises the step of dialyzing said electrolyte by applying a polarizing current, said cathode and said second anode connected to a source of said polarizing current and said cathode and said first anode connected to a source of pulsed current.

37. The method of Claim 36, wherein said membrane is an ion exchange membrane.

38. The method of Claim 36, wherein said membrane is a liquid permeable membrane.

39. The method of Claim 36, wherein filaments protrude from the surface of said first anode.

40. The method of Claim 36, wherein filaments protrude from the surface of said cathode.

41. The method of Claim 3, wherein said method is carried out in a compartmentalized reactor with a catholytic and an anolytic compartment separated by a membrane and having said cathode in said catholytic compartment and said anode in said anolytic compartment, further comprising the step of dialyzing the electrolyte by applying a polarizing current, said anode having filaments protruding across said membrane into said catholytic compartment and said cathode and said anode connected to a source of said polarizing current and a source of pulsed current.

42. The method of Claim 41, wherein said membrane is an electroneutral porous membrane.

43. The method of Claim 41, wherein said membrane is an ion exchange membrane.

44. The method of Claim 41, wherein filaments protrude from said cathode.

45. Apparatus for producing energy from cold nuclear fusion, which comprises:

a) a vessel;

b) a cementation electrolyte contained within said vessel, wherein said cementation electrolyte comprises heavy water and a noble metal ion species;

c) a sacrificial metal located within said cementation electrolyte, wherein said sacrificial metal is less noble than said noble metal ion species; and

d) means for capturing energy resulting from nuclear fusion reactions in said vessel.

46. The apparatus of claim 45, wherein said cementation electrolyte further comprises an indifferent ion.

47. The apparatus of Claim 45, wherein said cementation electrolyte further comprises a promoter.

48. The apparatus of Claim 47, wherein said promoter is selected from the group consisting of $Cr_2O_7^{2-}$ and VO_4^{3-}.

49. The apparatus of Claim 45, wherein said cementation electrolyte further comprises a complexing agent.

50. The apparatus of Claim 45, wherein said cementation electrolyte further comprises an anion.

51. The apparatus of Claim 45, further comprising means for stirring said cementation electrolyte.

52. The apparatus of Claim 45, further comprising means for increasing the temperature of said cementation electrolyte.

53. The apparatus of Claim 45, wherein said heavy water comprises deuterium nuclei.

54. The apparatus of Claim 45, wherein said heavy water comprises tritium nuclei.

55. The apparatus of Claim 45, further comprising means for introducing a gas capable of providing a reducing atmosphere into said electrolyte.

56. The apparatus of Claim 45, wherein said cementation electrolyte further comprises fluidized noble metal particles.

57. The apparatus of Claim 45, further comprising means for adding fluid to said cementation electrolyte.

58. The apparatus of Claim 45, further comprising a cathodic material that is more noble than said sacrificial metal electrically connected to said sacrificial metal.

59. The apparatus of Claim 58, wherein said vessel comprises a sacrificial compartment containing said sacrificial metal in an electrolyte comprising a noble metal ion species and a cathodic material compartment containing said cathodic material in an electrolyte comprising heavy water.

60. The apparatus of Claim 59, wherein said sacrificial metal compartment and said cathodic material compartment are separated by a membrane comprising said cathodic material.

61. The apparatus of Claim 58, wherein said cathodic material is permeable to liquids.

62. Apparatus for producing energy from cold nuclear fusion, which comprises:

a) a vessel;

b) an electrolyte contained within said vessel, wherein said electrolyte comprises heavy water;

c) at least one anode and at least one cathode, wherein said electrodes are located within said electrolyte;

d) means for supplying an electrical current between said at least one anode and said at least one cathode, wherein said current induces a migrational transport layer adjacent to said at least one cathode; and

f) means for capturing energy resulting from nuclear fusion reactions in said vessel.

63. The method of Claim 62, wherein said current is pulsed.

64. The apparatus of claim 62, wherein said electrolyte further comprises an indifferent ion.

65. The apparatus of Claim 62, wherein said electrolyte further comprises a promoter.

66. The apparatus of Claim 62, wherein said promoter is selected from the group consisting of $Cr_2O_7^{2-}$ and VO_4^{3-}.

67. The apparatus of Claim 62, wherein said electrolyte further comprises a complexing agent.

68. The apparatus of Claim 62, wherein said electrolyte further comprises an anion.

69. The apparatus of Claim 62, further comprising means for stirring said electrolyte.

70. The apparatus of Claim 62, further comprising means for increasing the temperature of said electrolyte.

71. The apparatus of Claim 62, wherein said heavy water comprises deuterium nuclei.

72. The apparatus of Claim 62, wherein said heavy water comprises tritium nuclei.

73. The apparatus of Claim 62, further comprising means for introducing a gas capable of providing a reducing atmosphere into said electrolyte.

74. The apparatus of Claim 62, wherein said electrolyte further comprises fluidized noble metal particles.

75. The apparatus of Claim 62, further comprising means to add fluid to said cementation electrolyte.

76. The apparatus of Claim 62, wherein said at least one cathode is permeable to liquids.

77. The method of Claim 62, further comprising:

a) a membrane separating said vessel into anolytic and catholytic compartments;

b) said at least one cathode and a first said anode located in said catholytic compartment;

c) a second said anode located in said anolytic compartment, wherein said means for supplying current comprises means for connecting electrically polarizing current between said cathode and said second anode and means for connecting electrically pulsed current between said cathode and said first anode.

78. The apparatus of Claim 77, wherein said membrane comprises an ion exchange membrane.

79. The apparatus of Claim 77, wherein said membrane comprises a liquid permeable membrane.

80. The apparatus of Claim 77, further comprising filaments protruding from said first anode.

81. The apparatus of Claim 77, further comprising filaments protruding from said cathode.

82. The method of Claim 62, further comprising:

a) a membrane separating said vessel into anolytic and catholytic compartments;

b) said at least one cathode located in said catholytic compartment;

c) said at least one anode located in said anolytic compartment;

d) filaments protruding from said at least one anode, wherein said filaments protrude from said at least one anode through said membrane; wherein said means for supplying a current comprise means for electrically connecting polarizing current between said at least one cathode and said at least one anode and means for electrically connecting pulsed current between said at least one cathode and said at least one anode.

83. The apparatus of Claim 82, wherein said membrane comprises an electroneutral porous membrane.

84. The apparatus of Claim 82, wherein said membrane comprises an ion exchange membrane.

85. The apparatus of Claim 82, further comprising filaments protruding from said cathode.

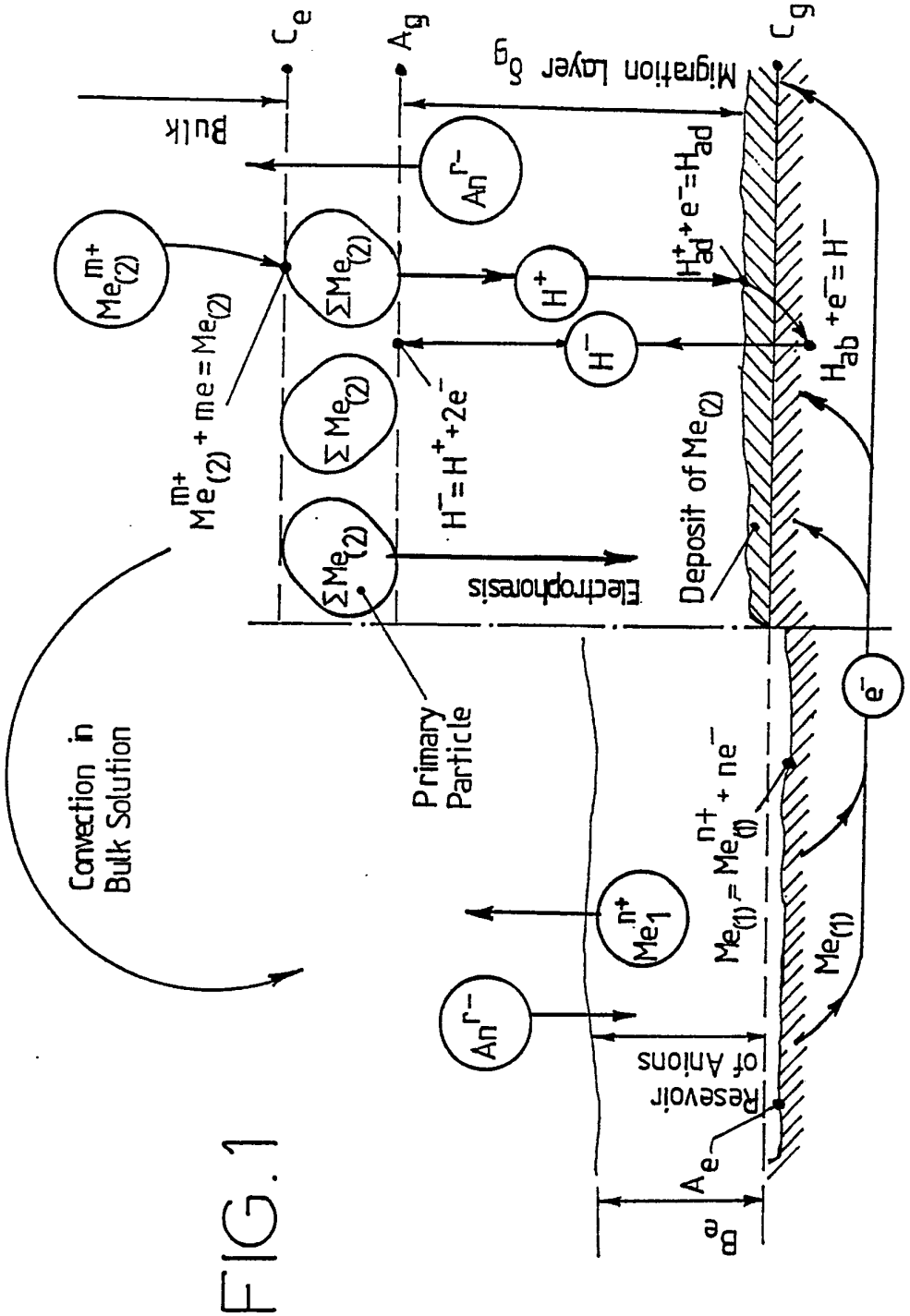

Bulk
Migration Layer δg
Electrophoresis
Deposit of Me(2)
Primary Particle
Convection in Bulk Solution
Reservoir of Anions
Ce
Ag
Cg
Ae
Be
Hab+e−=H−
Had+e−=Had
H−=H++2e−
Me(1)=Me(1)n+ + ne−
Me(2)m+ + me = Me(2)

FIG. 1

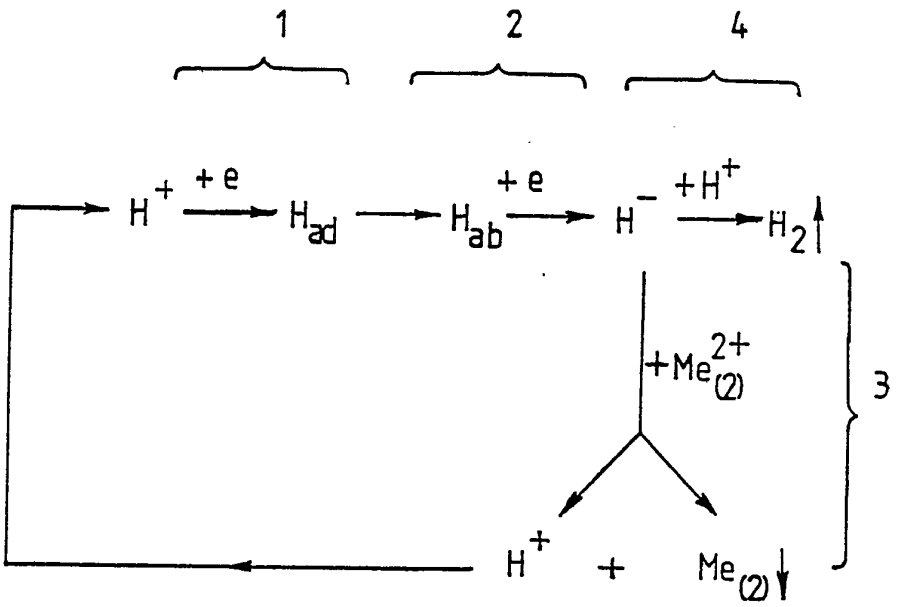

1
2
4
H+ +e Had
+e Hab
H− +H+ H2
+Me(2)2+
3
H+ + Me(2)

FIG. 3

FIG. 2

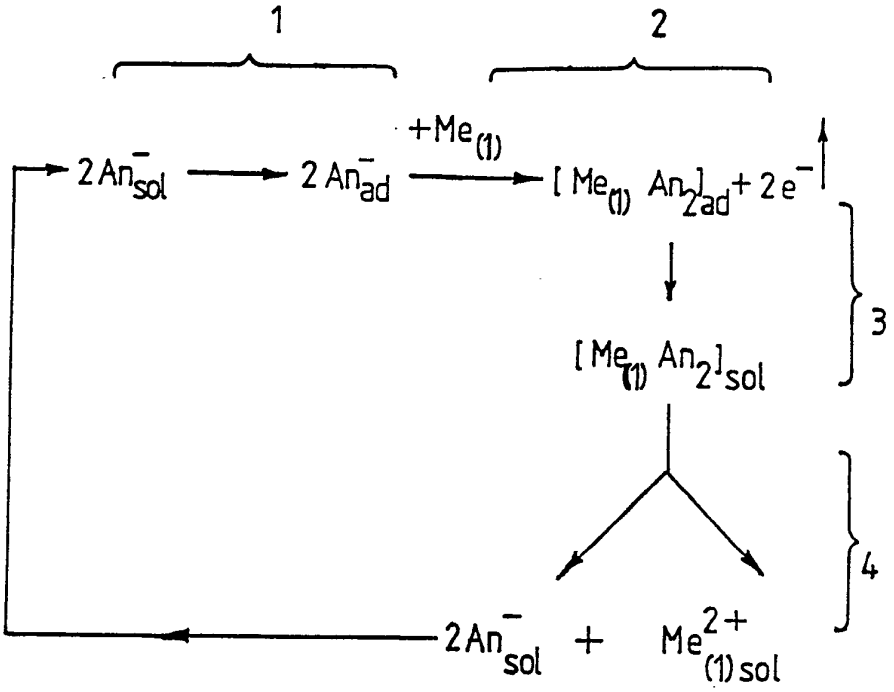

1
2
2 An−sol
2 An−ad
+Me(1)
[Me(1) An2]ad + 2e−
[Me(1) An2]sol
3
4
2 An−sol + Me(1) sol2+

FIG. 4

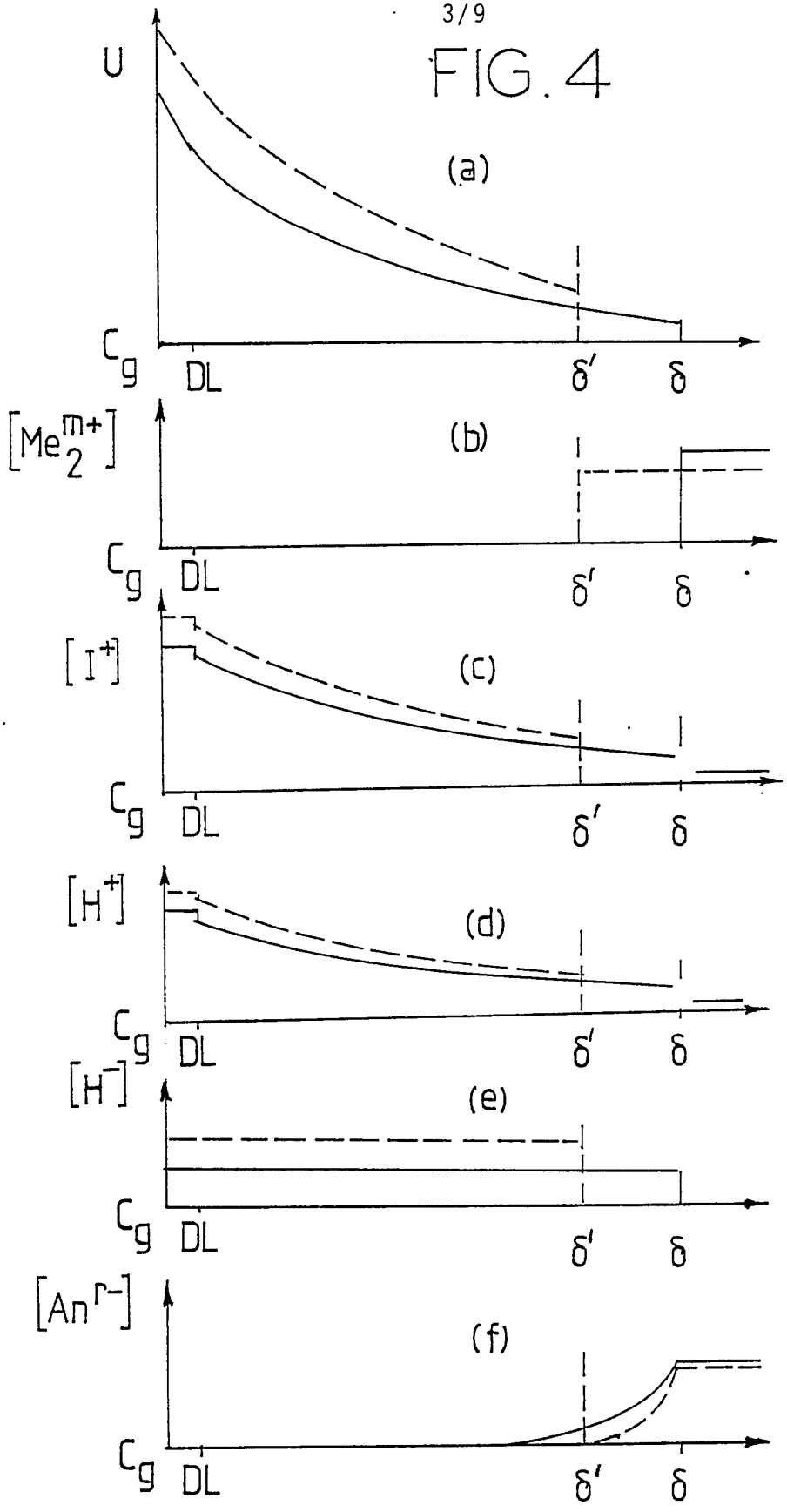

U
(a)
C_g
DL
δ′
δ
$[Me_2^{m+}]$
(b)
C_g
DL
δ′
δ
$[I^+]$
(c)
C_g
DL
δ′
δ
$[H^+]$
(d)
C_g
DL
δ′
δ
$[H^-]$
(e)
C_g
DL
δ′
δ
$[An^{r-}]$
(f)
C_g
DL
δ′
δ

FIG. 6

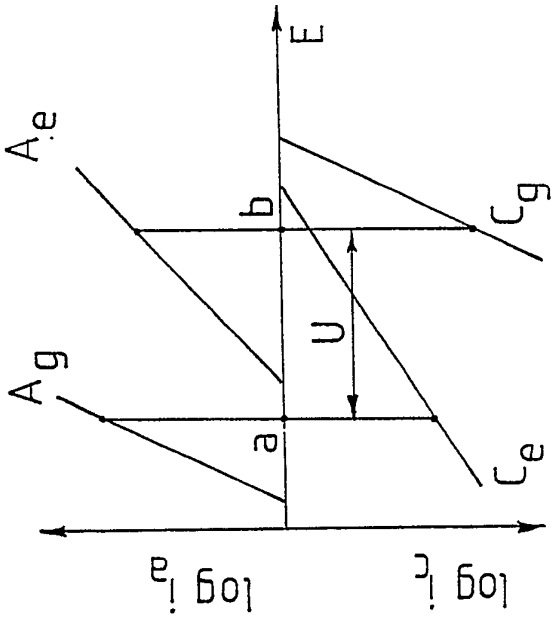
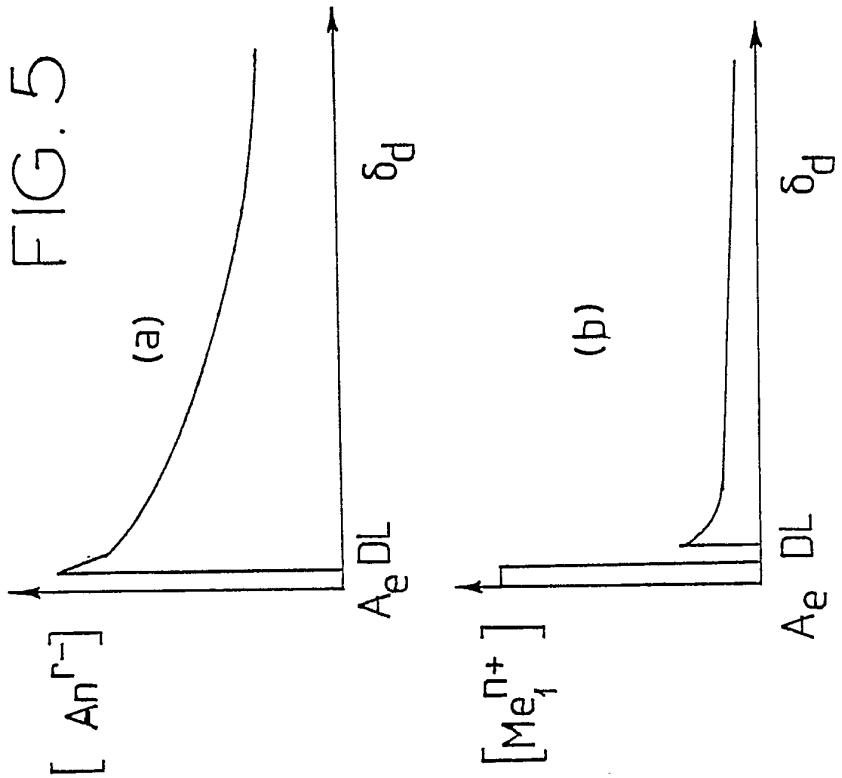

E
A_e
A_g
b
a
U
C_g
C_e
log i_a
log i_c

FIG. 5


(a)
δ_d
A_e DL
$[An^{r-}]$
(b)
δ_d
A_e DL
$[Me_1^{n+}]$

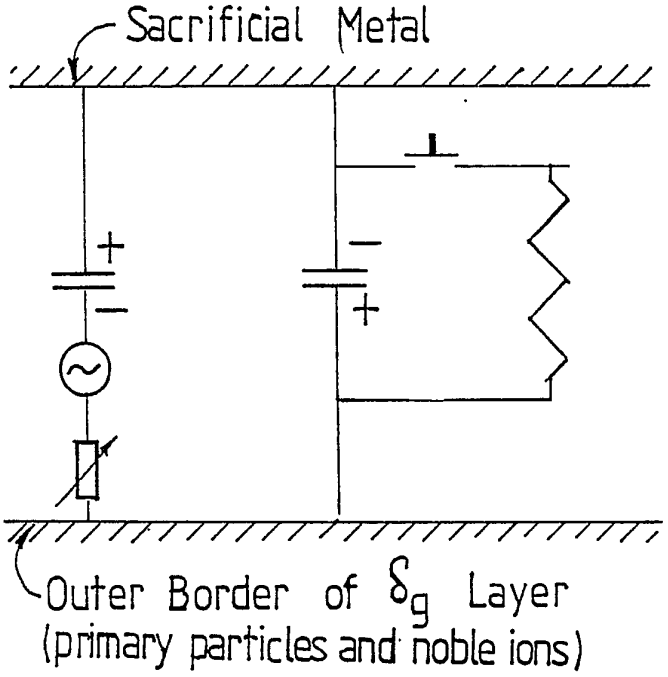

Sacrificial Metal
+
−
−
+
Outer Border of δ_g Layer
(primary particles and noble ions)

FIG. 7

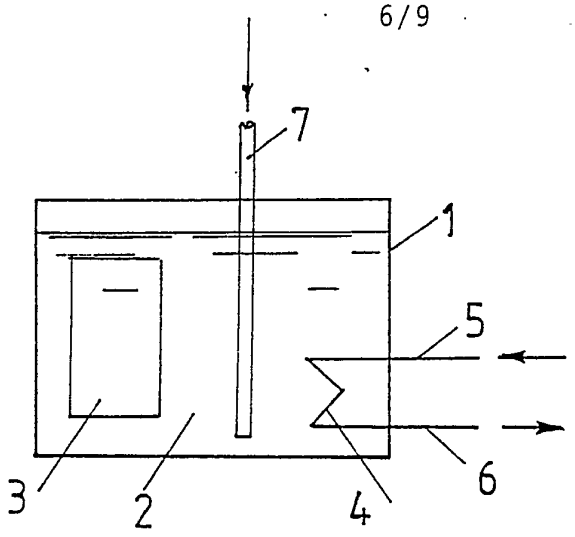


FIG. 8

FIG. 9

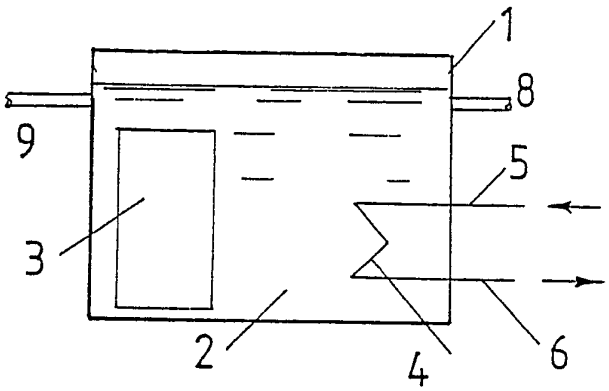
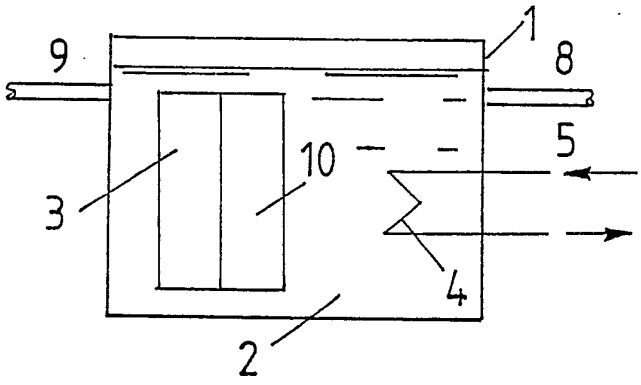


FIG. 10



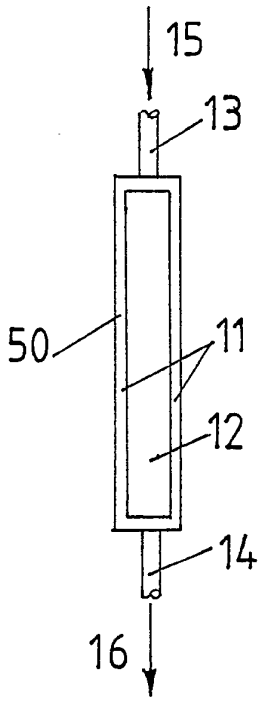
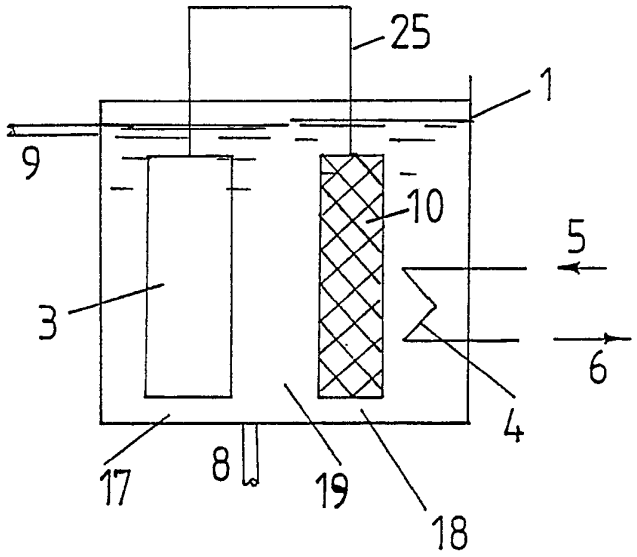


FIG. 11

FIG. 12



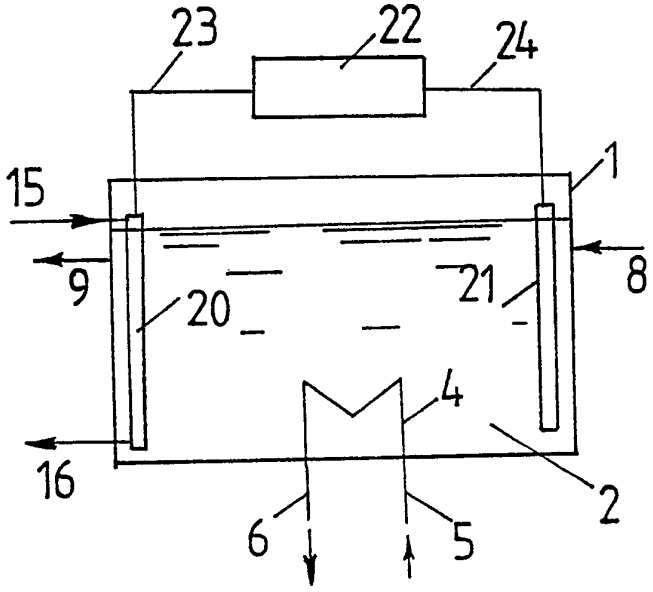
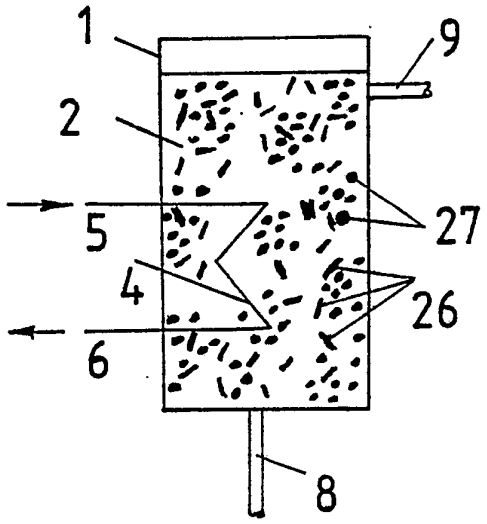


FIG. 13

FIG. 14



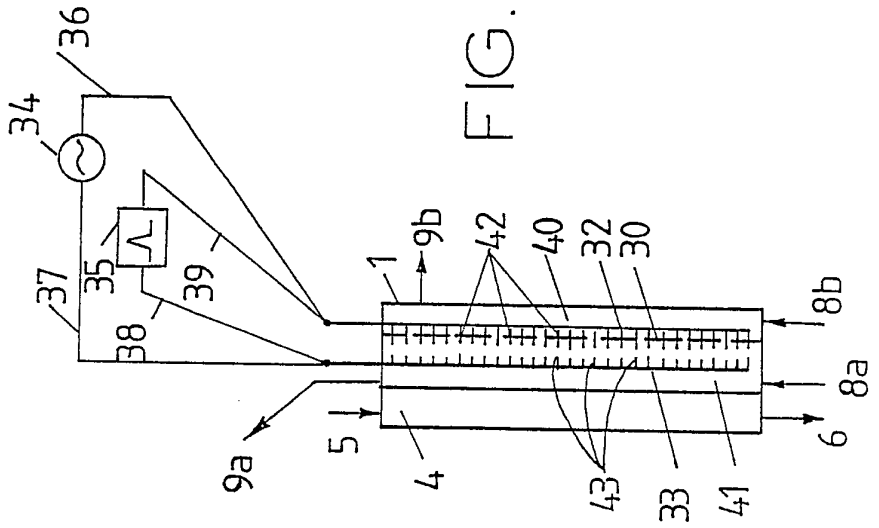

36
34
35
37
38
39
1
9b
42
40
32
30
8b
8a
6
5
9a
4
43
33
41

FIG. 16

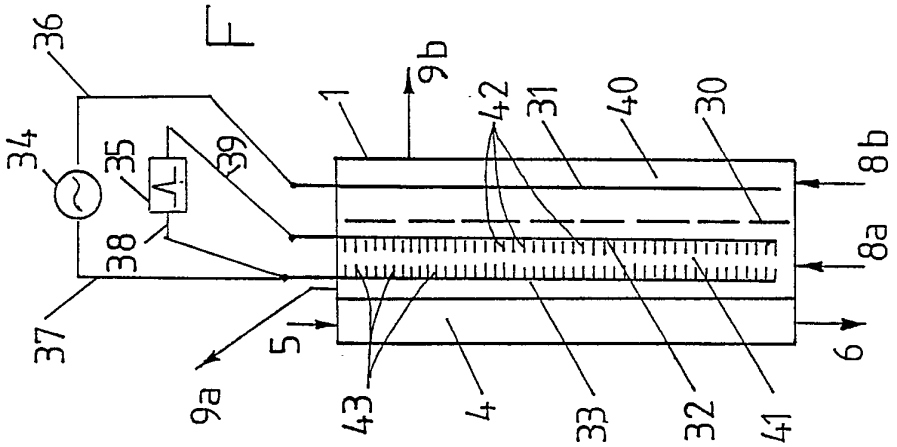

36
34
35
37
38
39
1
9b
42
31
40
30
8b
8a
6
5
9a
43
4
33
32
41

FIG. 15

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/01642

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): G21B 1/00
U.S. CL.: 376/100

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	376/100,146,114,115 204/129,290R, 290F, 291, 292, 293, DIG. *

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	WO, A, WO 90/10935 (PONS ET AL.) 20 September 1990; See all pages.	1-7,13-48,53-63, 65,66,71-85
Y	"Observation of cold nuclear fusion in condensed matter". Nature, Vol. 338, April 1989, pp. 737-740, JONES ET AL., see page 738, lines 24-33.	1-7,13-48,53-63, 65,66,71-85
Y	US, A, 3,288,694 (BANKS) 29 November 1966; Col. 5, lines 27-38.	22,33
Y	US, A, 4,784,730 (WILLIS ET AL.) 15 November 1988; Figure 1.	24,31
Y	US, A, 4,311,569 (DEMPSEY ET AL.) 19 January 1982; Col. 7, lines 18-22.	24,31
Y	US, A, 3,446,725 (SPANGLER ET AL.) 27 May 1969, col. 2, lines 27-70.	24.25,31-33
L	Nature, vol. 344, pp. 401-405, 29 March 1990, SALAMON ET AL.; cited as casting doubt on inducing cold neclear fusion.	1-7,13-48,53-63, 65,66,71-85

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
17 JUNE 1991	27 JUN 1991
International Searching Authority	**Signature of Authorized Officer**
ISA/US	DANIEL WASIL

Form PCT/ISA/210 (second sheet) (Rev.11-87)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

L	ORNL/FTR-3341, pp. 1-17, 31 July 1989, COOKE; cited as casting doubt on inducing cold nuclear fusion.	1-7,13-48,53-63, 65,66,71-85

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ...., because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☐ Claim numbers_____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

SEE ATTACHMENT

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

1-7, 13-48, 53-63, 65, 66, 71-85 (Inventions I1, I2, and II2).

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Continuation of PCT/ISA/210 item VI
"Observations where unity of invention is lacking"

The claims lack unity under PCT Rule 13 between the following independent and distinct species :

I. The embodiment including cementation by itself (claims 1,2,5-61).
II. The embodiment including applied outside current (claims 1,3,4,62-85).

SPECIES I If species I is elected, then applicants are further required to elect one of the following species.
The embodiment wherein the intensity of the local electromagnetic field is increased by :
I1. indifferent ions; claims 1,2,5,13-46,53-61
I2. promoters; claims 1,2,6,7,13-45,47,48,53-61
I3. complexing agents; claims 1,2,8,13-45,49,53-61
I4. temperature increase; claims 1,2,9,13-45,52-61
I5. anions; claims 1,2,10,13-45,50,53-61
I6. optimizing mixing rate; claims 1,2,11,13-45,51,53-61
I7. non smooth cathode surface; claims 1,2,12-45,53-61

SPECIES II If species II is elected, then applicants are further required to elect one of the following species.
The embodiment wherein the intensity of the local electromagnetic field is increased by :
II1. indifferent ions; claims 1,3,4,62-64,71-85
II2. promoters; claims 1,3,4,62,63,65,66,71-85
II3. complexing agents; claims 1,3,4,62,63,67,71-85
II4. anions; claims 1,3,4,62,63,68,71-85
II5. optimizing mixing rate; claims 1,3,4,62,63,69,71-85
II6. temperature increase; claims 1,3,4,62,63,70-85